OPTIMIZING THE CONSTRUCTION PLANNING OF HIGHWAY WORK ZONES

BY

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DISSERTATION

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ABSTRACT

Highway work zones often cause traffic congestions and delays resulting in increased road user delay, traffic crashes, and vehicle emissions. The Federal Highway Administration (FHWA) and state DOTs are continuously seeking to improve work zone safety and mobility. To accomplish this, the layout of highway work zones needs to be carefully planned and optimized to accomplish the multiple and often conflicting objectives of maximizing safety and mobility while minimizing cost. This can be achieved by identifying an optimal solution for work zone layout decisions such as the length of work zone segments, work zone speed limit, nighttime work hours, temporary utilization of shoulder for traffic, and the use of flaggers, spotters, and/or other temporary traffic control (TTC) measures.

The main goal of this research study is to develop multi-objective models for optimizing the planning of highway work zones that are capable of striking an optimal balance among the critical and often conflicting objectives of maximizing work zone safety, maximizing traffic mobility, and minimizing construction cost. To accomplish this goal, the research objectives of this study are to (1) perform field studies to evaluate the effectiveness of current TTC practices and work zone layout parameters in improving safety and mobility; (2) collect and analyze the latest available data on work zone crashes to study the frequency and severity of traffic-related work zone crashes, and investigate the probable causes and contributing factors of these crashes; (3) conduct surveys of DOT resident engineers and highway contractors to gather their feedback on the effectiveness and benefits of TTC measures and other layout parameters such as flaggers, spotters, and other TTC devices; (4) develop a novel multi-objective

optimization model for highway work zone layouts that is capable of generating optimal tradeoffs between minimizing traffic delays and minimizing construction cost; and (5) create an innovative multi-objective optimization model to search for and identify a set of Pareto optimal work zone layouts that provide a wide range of optimal tradeoffs between minimizing traffic delays and minimizing probability of crashes.

The performance of the developed optimization models was analyzed and verified using case studies of work zone layouts. The results of analyzing these case studies illustrated the novel and unique capabilities of the developed models in searching for and identifying optimal work zone layouts. These new and unique capabilities are expected to support state DOTs and construction planners in their ongoing efforts to (i) maximize work zone safety, (ii) reduce traffic delays in the work zone area, and (iii) minimize work zone construction cost.

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CHAPTER 1
INTRODUCTION

1.1. PROBLEM STATEMENT

The number of work zones in the US has increased in recent years to upgrade and expand the aging network of highways and roads (Oh, et al. 2011). These work zones require lane closures during construction and accordingly they cause traffic congestions and delays resulting in increased road user delay, traffic incidents, and vehicle emissions (Borchardt et al. 2009, Du and Chien 2014). Work zones are estimated to account for approximately 10% of the overall congestion on highways, nearly 24% of highway non-recurring delays, and about 482 million hours of annual traffic delays (FHWA 2014). In addition, a total of 28,852 crashes were reported in and around work zones on highways during the period from 1996 to 2009 that caused 148 fatalities, 7,087 serious injuries, and 21,617 property damages (NHTSA 2010).

To address the aforementioned mobility and safety issues in highway work zones, the Federal Highway Administration (FHWA) updated the work zone regulations to provide high level of safety for workers and public, maximize mobility, and minimize congestion and other negative impacts to community. The Work Zone Safety and Mobility Rule was published by FHWA (2004) to require every state to develop safety and mobility policies. State DOTs such as the Illinois Department of Transportation IDOT developed policies to reach safety and mobility goals including: (1) zero worker fatalities, (2) reduce work zone crashes and number of motorists’ fatalities in work zone related crashes, and (3) minimize delay due to work zones to be less than 5 minutes per mile (IDOT 2007).

To support the implementation of the aforementioned critical federal and state policies, the layout of highway work zones needs to be carefully designed and optimized to accomplish the multiple and often conflicting objectives of maximizing safety and mobility while minimizing public cost. These three critical work zone objectives can be optimized by identifying an optimal work zone layout. This requires planners to identify an optimal solution for each related work zone layout decision/parameter such as the using flaggers, spotters, and/or other temporary traffic control (TTC) measures, determining the length of work zone segments, performing the work during low traffic periods such as nighttime, and utilizing the shoulder (Du and Chien 2014, Jiang and Adeli 2003, Bai and Li 2006, McCoy and Mennenga 1998).

Each of the aforementioned work zone layout parameters has varying individual and collective impacts on the aforementioned three objectives of mobility, safety, and cost. Accordingly, the individual and collective impacts of these measures on these critical optimization objectives need to be investigated and optimized. For example, the individual and collective impact of using flaggers and/or spotters in highway work zones on mobility, safety and cost needs to be investigated to enable the optimization of work zone layout planning. Utilizing flaggers in highway work zones as recommended by many existing DOT standards introduces inherent risks due to the positioning of flaggers near active traffic lanes. To minimize these risks, other innovative TTC devices and/or spotters can be used instead of flaggers to observe traffic in the operation area from a safe distance from live traffic lanes and alert workers to any perceived dangerous conditions.

To support the aforementioned federal and state policies that seek to maximize work zone safety, mobility and cost-effectiveness, there is a pressing need to conduct in-depth research to (1) investigate the effectiveness and risks of relevant work zone layout parameters such as using spotters, flaggers and other TTC devices in highway work zones, (2) develop a multi-objective optimization model to identify optimal tradeoffs between minimizing traffic delays and construction cost, and (3) develop a multi-objective optimization model to identify optimal tradeoffs between minimizing the probability of work zone crashes and traffic delays.

1.2. RESEARCH OBJECTIVES

The main goal of this study is to optimize the layout planning of highway work zones in order to maximize mobility and safety while minimizing construction cost. To accomplish this critical goal, the objectives of the research are:

Objective 1

Conduct a comprehensive literature review to study the latest research on quantifying and optimizing the impact of work zone layout parameters and TTC measures on work zone safety, mobility and cost.

Research Questions

(a) what are the work zone layouts and strategies used in highway work zones? (b) what are the current work zone safety and mobility policies? (c) What are the effectiveness of the latest TTC devices that can be used in highway work zones and their impact on safety and mobility? (d) what are the effectiveness and risks of using flaggers and spotters in highway work zones? and (e) what are the latest research on the impact of highway work zone layout parameters on safety and mobility?

Objective 2

Perform field studies to evaluate the effectiveness of current TTC practices and work zone layout parameters in improving safety and mobility.

Research Questions

(a) What are the main causes of work zone crashes and delays? (b) what are the TTC devices and layout parameters that can enhance safety and mobility? (b) what are the impacts of flaggers and other TTC on the behavior and speed of traffic? (c) what are the used TTC measures to assist access to and egress from highway work zones? (d) what is the effectiveness of using flaggers and/or spotters at the access and egress points of work zones? (e) How are flaggers currently used in highway work zones and what are the types of risks they are being exposed to due to their positioning close to live traffic lanes? and (f) what is the feasibility of using sound alarms to warn the workers in highway work zones?

Objective 3

Collect and analyze the latest available data on work zone crashes in Illinois during a 14-year period to study the frequency and severity of traffic-related work zone crashes in Illinois highways, and investigate the probable causes and contributing factors of these work zone crashes.

Research Questions

(a) What is the impact of work zone layout parameters such as traffic control and light conditions on the frequency and severity of work zone crashes on highways? (b) what are the probable causes and factors contributing to work zone crashes? and (c) what are the probability of crashes that are associated with each layout parameters and TTC?

Objective 4

Conduct a survey of DOTs resident engineers and highway contractors to gather their feedback on the effectiveness and benefits of TTC measures and other layout parameters such as flaggers, spotters, and other TTC devices.

Research Questions

(a) What are the needs and benefits of using flaggers and/or spotters in highway work zones? (b) what are the types and levels of risks caused by using flaggers and/or spotters in these types of work zones? (c) what are the effectiveness of existing and new safety devices that can be used to enhance work zone safety and mobility? and (d) What are the effectiveness of current and innovative access and egress plans to improve work zone safety and mobility?

Objective 5

Develop a novel multi-objective optimization model to generate optimal tradeoffs between minimizing traffic delays and construction cost by identifying optimal solutions for all related work zone layout parameters such as segment length, starting time, shoulder use, lateral clearance, and work zone access.

Research Questions

(a) What are the decision variables and constraints that best represent the optimal layout parameters of work zones on highways? (b) How to formulate a multi-objective optimization model to generate optimal tradeoffs among delay and cost objectives? and (c) what are the most effective optimization techniques to generate optimal tradeoffs between the delay and cost objectives for highway work zones?

Objective 6

Develop an innovative multi-objective optimization model to generate optimal tradeoffs between minimizing traffic delays and probability of crashes by identifying optimal solutions for all related work zone layout parameters such as segment length, starting time, posted speed limit, shoulder use, lateral clearance, TTC measures, type of barriers, and work zone access.

Research Questions

(a) What are the decision variables and constraints that best represent the optimal layout parameters and safety measures of work zones on highways? (b) How to formulate a multi-objective optimization model to generate optimal tradeoffs among mobility and risk objectives? (c) what are the most effective optimization techniques to generate optimal tradeoffs between the risk and mobility objectives for highway work zones? and (d) what are the optimal layout parameters and TTC devices that minimize delay and cost objectives?

1.3. RESEARCH METHODOLOGY

To accomplish the aforementioned objectives of this study, a research methodology is proposed as shown in Figure 1.1. The methodology consists of seven major research tasks: (1) conduct a comprehensive literature review; (2) perform site visits and field studies of highway work zones; (3) collect and analyze the latest data on work zone crashes in Illinois; (4) conduct survey of officials in IDOT and other state DOTs; (5) investigate effectiveness of work zone innovative safety measures; (6) develop an optimization model to minimize work zone delays and cost; and (7) develop an optimization model to minimize work zone delays and probability of crashes.

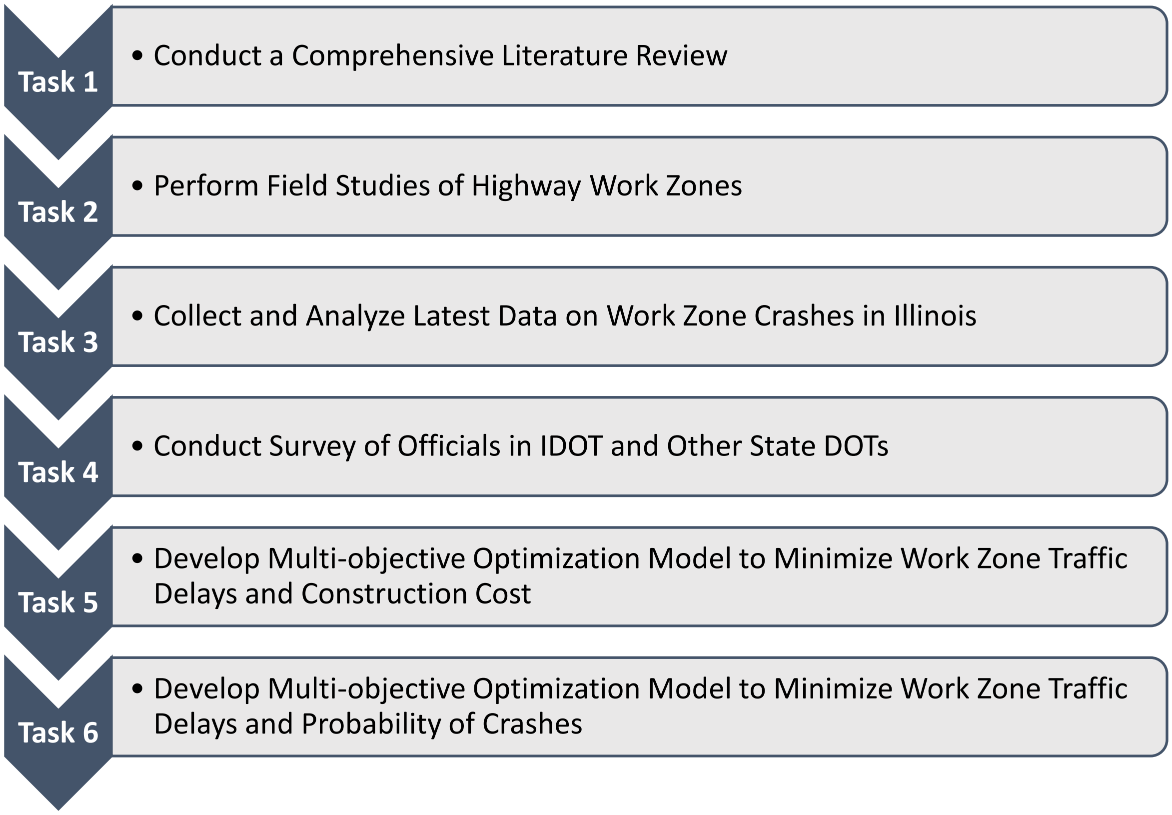

Figure 1.1. Research Methodology

Task 1: Conduct a Comprehensive Literature Review

In this task, a comprehensive literature review will be conducted to study the latest research and developments on the impact of highway work zone layout parameters and TTC measures on safety and mobility. This review will cover current practices and recent research in this area, including (1) work zone layouts and strategies used in highway work zones; (2) the current work zone safety and mobility policies; (3) the effectiveness of the latest TTC devices that can be used in highway work zones and their impact on safety and mobility such as: intrusion alarms, Truck Mounted Attenuator (TMA), Portable Changeable Messages Sign (PCMS), and Speed displays; (4) the effectiveness and risks of using flaggers and spotters in highway work zones; and (5) the latest research on the impact of highway work zone layout parameters and TTC measures on safety and mobility.

Task 2: Perform Field Studies of Highway Work Zones

In this task, a number of selected work zones in Illinois were visited to conduct field studies to evaluate current layout design, TTC measures and safety device that are used in highways work zones. During these site visits, field data were gathered on (1) typical work zone layouts and TTC; (2) the type of construction operations being performed in the work zone; (3) The role and the location of flaggers and spotters in directing traffic in work zone area and in controlling access and egress of work zones; (4) evaluate and quantify the delay of using flaggers and spotter in access and egress from work zone; and (5) work zone safety measures such as intrusion alarms, PCMS, and Speed displays.

Task 3: Collect and Analyze Latest Data on Work Zone Crashes in Illinois

This research task focused on gathering and fusing the latest data and reports on work zone crashes from all available sources and all types of roads and highways in Illinois for at 14-year period, where relevant data are readily available. The sources of data include (1) the National Highway Traffic Safety Administration (NHTSA) that provides a wide range of data for each recorded work zone crash, including crash severity, number of fatalities and injuries, work zone type, traffic volume (AADT), road classification, used traffic control measure, time and day, light conditions, and weather data (NHTSA 2012); and (2) police reports that provide additional data on work zone configuration. The collected data was analyzed and fused to identify: (i) impacts of work zone layout parameters such as traffic control and light conditions on the frequency and severity of work zone crashes on highways; (ii) main causes and factors contributing to work zone crashes; and (iii) probability of crashes that are associated with each layout parameter and TTC.

Task 4: Conduct Survey of Officials in IDOT and Other State DOTs

In this task, two identical online surveys were conducted to gather and analyze feedback from engineers and construction personnel in IDOT and other state DOTs on the effectiveness temporary traffic control devices and the use of flaggers and spotters on highway work zones. The survey was distributed to IDOT resident engineers, managers, supervisors, maintenance personnel, contractors, and consultants. Another version of the survey was also distributed to other state DOTs. Both surveys are identical and consist of three main sections. The first section focus on identifying the need, benefits, and risks of using flaggers in and around work zones. The second section evaluates spotter functions, benefits, and risks. The third section aims to collect feedback from survey respondents on the effectiveness, need, and risks of using spotters instead of flaggers in work zones. The fourth section evaluates the effectiveness of using various safety measures including temporary traffic control (TTC) devices and other measures to improve the safety of work zone access and egress points.

Task 5. Develop Multi-objective Optimization Model to Minimize Work Zone Traffic Delays and Construction Cost

The task focuses on developing a model that is designed to optimize work zone layout parameters including: work zone segment length, starting time, shoulder use, lateral clearance, and work zone access to minimize the construction cost and delay. The model is developed in four main phases: (1) decision variables identification phase that identifies all relevant decision variables; (2) model formulation phase that specifies the model decision variables, objective functions, and constraints; (3) implementation phase that performs the optimization computations using multi-objective genetic algorithms and specifies the model input and output; and (4) performance evaluation phase that analyzes the performance of the developed model. The output of this model will be optimum layout parameters for work zones on highways and the optimal tradeoffs between construction coat and delay.qw3

Task 6. Develop Multi-objective Optimization Model to Minimize Work Zone Traffic Delays and Probability of Crashes

The task will develop a model that designed to optimize work zone layout parameters and TTC measures including: work zone speed limit, starting time, shoulder use, lateral clearance, work zone segment length, TTC measures, and work zone access to minimize the probability of crashes and delay. The model is developed in four main phases: (1) decision variables phase that identifies all relevant work zone layout variables that affect both the safety and mobility of highway work zones; (2) objective functions phase that formulates two objective functions that quantify and optimize the impact of all the identified work zone decision variables on work zone safety and traffic mobility; (3) constraints phase that models all relevant and practical constraints that affect this optimization problem; and (4) implementation phase that performs the model optimization computations using multi-objective genetic algorithms and specifies the model input and output. The output of this model will be optimum layout and TTC measures for work zones on highways and the optimal tradeoffs between traffic delays probability of crashes.

1.4. REPORT ORGANIZATION

This preliminary exam report includes the findings of the aforementioned research tasks 1, through task 5. Chapter 2 provides a comprehensive review of the latest literature on the impact of layout parameters and effectiveness of TTC measures and safety devices in highways work zones. Chapter 3 provides the findings of seven field studies in work zones in Illinois that were conducted to evaluate current TTC measures and safety devices. Chapter 4 presents the findings of a comprehensive analysis of work zone crashes in Illinois during a fourteen-year period, from 1996 to 2009. Chapter 5 presents the results of two surveys that were conducted to gather and analyze feedback from engineers and construction personnel in IDOT and other state DOTs on the effectiveness of TTC devices and the use of flaggers and spotters on highway work zones. Chapter 6 presents the developing of a novel multi-objective optimization model to identify optimal tradeoffs between minimizing traffic delays and construction cost. Chapter 7 presents the developing of a novel multi-objective optimization model to identify optimal tradeoffs between minimizing traffic delays and probability of crashes. Chapter 8 presents the summary and conclusion of the conducted research and the proposed future research ideas.

CHAPTER 2
LITERATURE REVIEW

2.1. INTRODUCTION

This literature review focuses on current standards and latest research on the impact of TTC measures and layout parameters on safety and mobility of highways work zones. The literature review is organized in six main sections: (1) work zone layouts and strategies; (2) work zone safety and mobility policies; (3) effectiveness of TTC devices; (4) effectiveness and risks of using flaggers; (5) use of spotters in work zones; and (6) impact of work zone layout parameters on mobility and cost.

2.2. WORK ZONE LAYOUTS AND STRATEGIES

2.2.1. Work Zone Layouts

The layout of a work zone must provide a clear separation between the travel and work activity spaces and provide buffer spaces for protecting motorists and workers who unintentionally stray from their intended work areas (Bryden and Mace 2002). The work zone is divided into four areas: (1) advance warning; (2) transition; (3) activity; and (4) termination as shown in Figure 2.1 (MUTCD 2009).

2.2.1.1. <u>Advance Warning Area</u>

The advance warning area is the section of roadway where road users are informed about the upcoming work zone. Since two or more advance warning signs are regularly used, the advance warning area should extend 1,500 ft. (450 m) or more for open highway conditions and it may extend on freeways and expressways as far as 0.5 mi (800 m) or more (MUTCD 2009). The effective placement of the first warning sign in advance of the taper in feet (meters) should be substantially long from 8 to 12 times the speed limit in mph (1.5 to 2.25 times the speed limit in km/h) (MUTCD 2009). The advance warning signs may vary from a single sign or high-intensity rotating, flashing, oscillating, or strobe lights on a vehicle to a series of signs in advance of the temporary traffic control (TTC) zone, as shown in Figure 2.1.

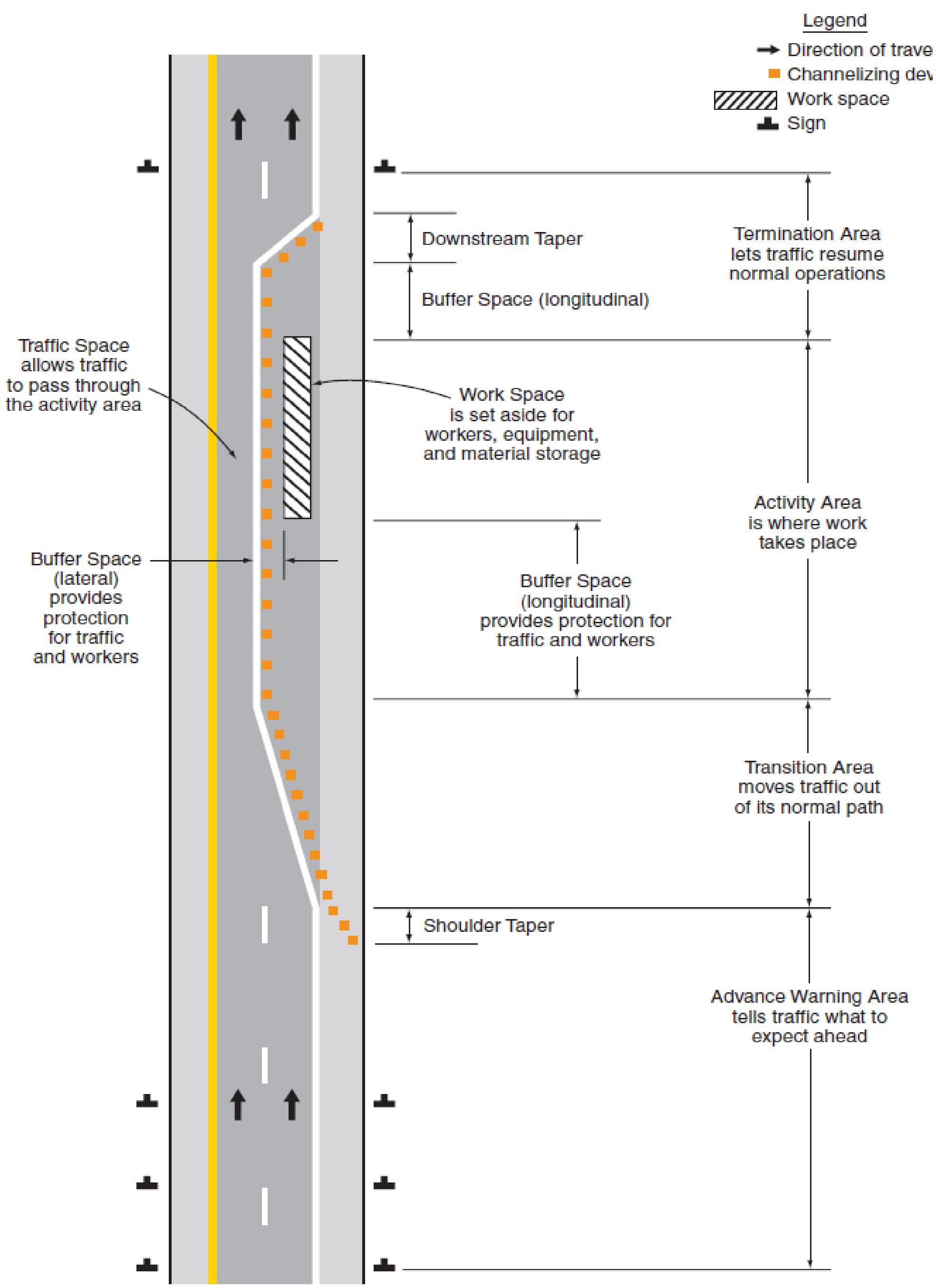

Figure 2.1. Major Components of a TTC Zone (MUTCD 2009)

2.2.1.2. Transition Area and Tapers

The transition area is the section of roadway where road users are redirected outside their normal path. Transition areas usually involve strategic use of tapers that are created by using a series of channelizing devices and in some cases pavement markings to move traffic from the normal path, as shown in the different types of tapers in Figure 2.3 Tapers may be used in both the transition and termination areas. The appropriate taper length (L) is determined using Table 2.1and Table 2.2, and the maximum distance in feet (meters) between devices in a taper should not exceed 1.0 times the speed limit in mph (0.2 times the speed limit in km/h) (MUTCD 2009). Whenever tapers are to be used in close proximity to an interchange ramp, crossroads, curves, or other influencing factors, the length of the tapers may be adjusted.

Table 2.1. Formulas for Determining Taper Length (MUTCD 2009)

Speed Limit (S)	**Taper Length (L)**
60 Km/h or less	L= $\frac{WS^2}{155}$ meters
70 km/h or more	L = $\frac{WS}{1.6}$ meters

Speed Limit (S)	**Taper Length (L)**
40 mph or less	L= $\frac{WS^2}{60}$ feet
45 mph or more	L = *WS* feet

Where: L = taper length; S = posted speed limit; W = width of offset

Table 2.2. Taper Length Criteria for TTC Zone (MUTCD 2009)

Type of Taper	**Taper length (L)**
Merging Taper	At least L
Shifting Taper	At least 0.5L
Shoulder Taper	At least 0.33L
One-Lane, Two-Way Traffic Taper	100 ft (30 m) maximum
Downstream Taper	100 ft (30 m) per lane

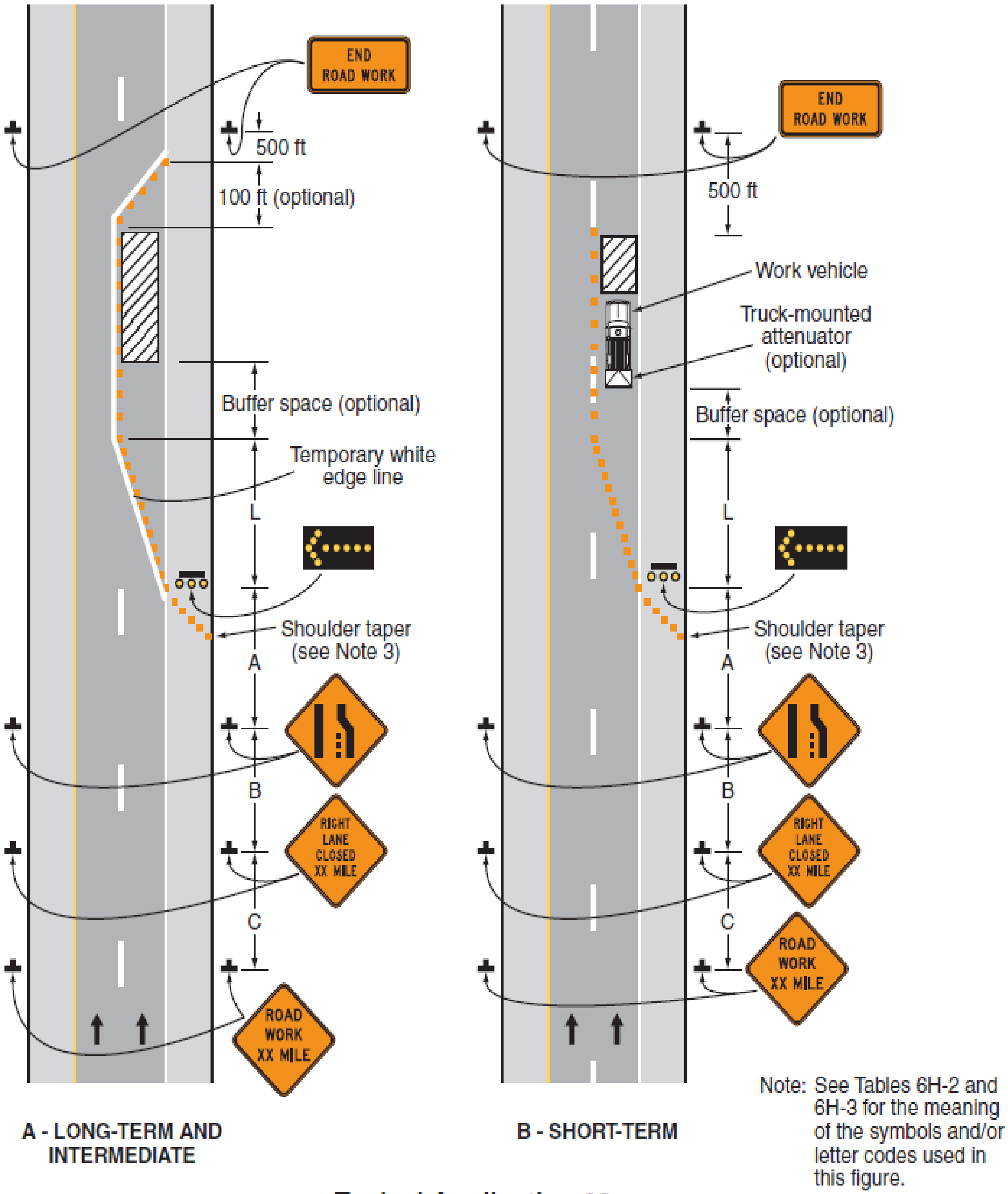

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Figure 2.2. Stationary Lane Closure on a Divided Highway (MUTCD 2009)

2.2.1.3. Activity Area

The activity area is the section of the roadway where the work activities take place. It comprises of the work space, the traffic space, and the buffer space, as shown in Figure 2.3. The work space could be stationary or mobile depending on the progress of work. The traffic space allows traffic to pass through the activity area. The buffer space is a lateral and/or longitudinal area that separates road user flow from the work space and it provides recovery space for an errant vehicle, as shown in Figure 2.3. The allowable length of the longitudinal buffer is determined based on the allowable stopping sight distance which varies according to the design speed (MUTCD 2009).

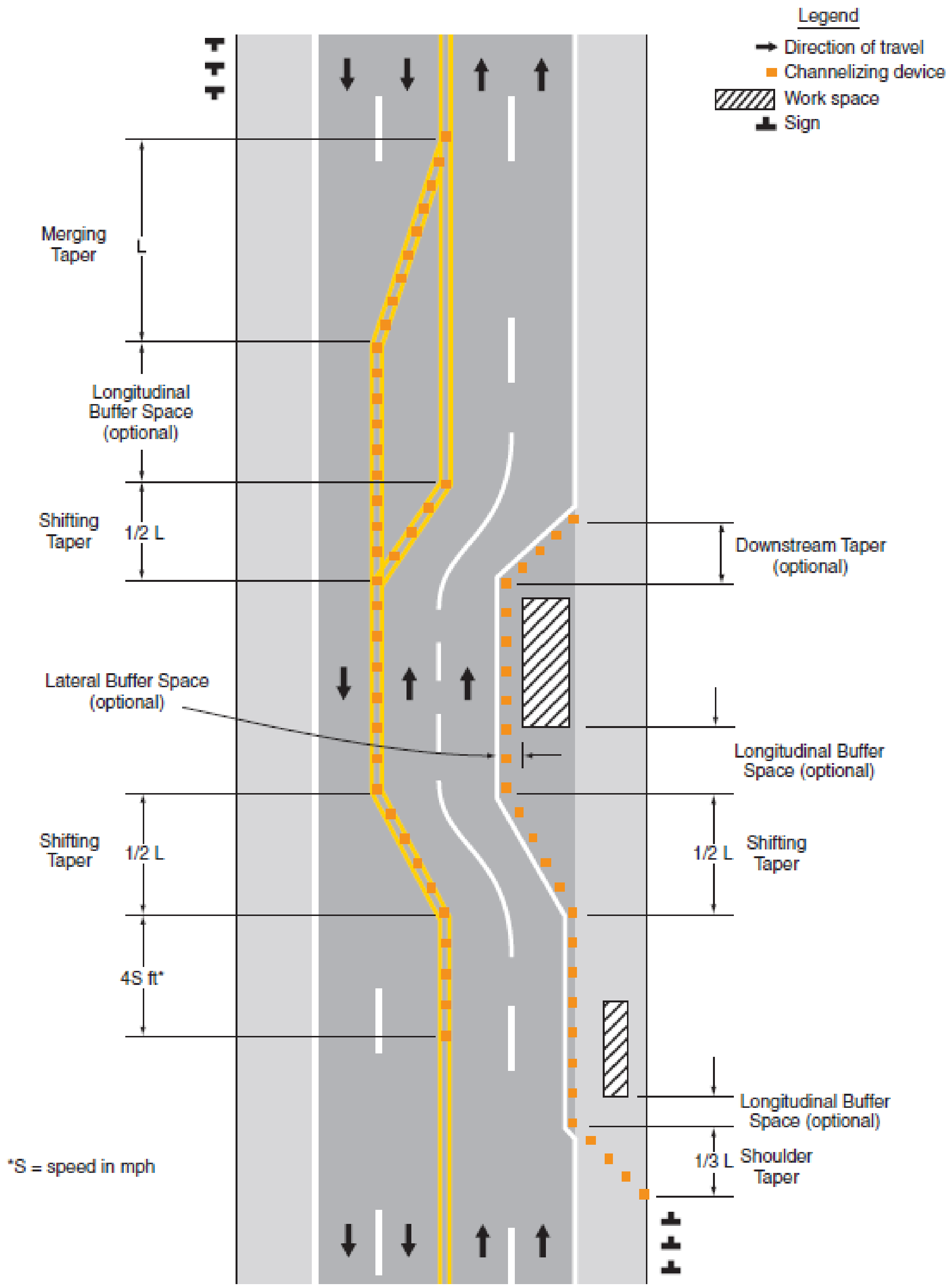

Figure 2.3. Types of Tapers and Buffer Spaces (MUTCD 2009)

2.2.1.4. Termination Area

The termination area is the section of the roadway that returns road users to their normal driving path. It extends from the downstream end of the work area to the last temporary traffic control (TTC) device. An “END ROAD WORK” sign, a “Speed Limit” sign, or other signs may be used to inform road users that they can resume normal operations and a longitudinal buffer space may be used between the work space and the beginning of the downstream taper.

2.2.2. Work Zone Strategies

A work zone strategy is developed to carry traffic through or around the facility under construction via a system of infrastructure and a set of temporary traffic controls (Mahoney et al. 2007). Nine strategies are widely employed for construction work zones on highways, and are outlined in the transportation management plans (TMP) for specific projects (IDOT 2002; Mahoney et al. 2007). These strategies include: (1) alternating one-way operation; (2) detour; (3) diversion; (4) full road closure; (5) intermittent closure; (6) lane closure; (7) lane constriction; (8) median crossover; and (9) use of shoulder. Each of these nine strategies has its own basic characteristics and offers a unique set of advantages and disadvantages as summarized in Table 2.3 (Mahoney et al. 2007). The selection process of a work zone strategy is governed by many factors such as the number of lanes, geometric and structure design, highway and worker safety, accessibility, capacity and queues, constructability, and cost consequences (Mahoney et al. 2007).

Table 2.3. Advantages and Disadvantages of Work Zone Strategies (Mahoney et al. 2007

Strategy	Summary	Advantages	Disadvantages
Alternating one-way operation	Mitigates for full or intermittent closure of lanes. Used primarily with two-lane facilities.	Low agency cost and low non-transportation impacts; flexible, several variations available.	Requires stopping of traffic; reduces capacity.
Detour	Reroutes traffic onto other existing facilities.	Flexible: cost varies depending on detour route improvements; in some cases, only TTC needed.	Usually reduces capacity; service and infrastructure on existing roads may be degraded; may need agreement of another agency.
Diversion	Provides a temporary roadway adjacent to construction.	Separates traffic from construction: reduced impact on traffic.	Cost may be substantial, especially if temporary grade separation of hydraulic structure involved; right-of-way often required.
Full road closure	Closes the facility to traffic a specified (limited) duration.	Generally also involves expedited construction; separates traffic from construction	Some form of mitigation is needed (detour, diversion, etc.); potentially significant traffic impacts.
Intermittent closure	Stops traffic for a short period.	Flexible and low agency cost.	Useful only for activities that can be completed in short time; requires stopping traffic.
Lane closure	Closes one or more travel lanes.	Maintains service; fairly low agency cost if temporary barriers are omitted.	Reduces capacity; may involve traffic close to active work.
Lane construction	Reduces traveled way width.	Maximizes number of travel lanes.	Traveled way width is less than desirable; may involve traffic close to active work.
Median crossover	Maintains two-way traffic on one roadway of a normally divided highway.	Separates traffic from construction; right-of-way not required.	Reduced capacity; not consistent with approach roadway; relatively costly; interchanges need special attention.
Use of shoulder	Uses shoulder as a travel lane.	Fairly low cost, depending on shoulder preparation.	Displaces traditional refuge for disabled vehicles; debilitates shoulder pavement structure; cross slopes may be problematic.

2.3. WORK ZONE SAFETY AND MOBILITY POLICIES

Work zones have been recognized as hazardous locations for workers. An analysis of serious and fatal injuries to highway workers in New York (Bryden and Andrew 1999) found that 22% of all serious worker injuries and 43% of fatal worker injuries resulted from traffic crashes. It was also observed that two-thirds of the injuries to pedestrian workers occurred from vehicles intruding into marked workspaces and striking workers or flaggers. The proximity of workers and traffic is another concern that makes safety a high priority in highway work zones.

The FHWA is actively improving work zone safety and mobility through new regulations, better engineering, education, enforcement, and communication with concerned public safety agencies (FHWA 2009b). On September 9, 2004 the FHWA updated the work zone regulations at 23 CFR 630 Subpart J under the "Work Zone Safety and Mobility Rule" that affect all state projects as well as federal aid funded local highway projects starting on October 12, 2007 (Scriba et al. 2005). The main goal of the updated rule is to reduce work zone crashes and congestion at three main implementation levels: (1) policy-level by developing general work zone policies that suit state transportation agencies; (2) process-level by developing agency's work zone processes and procedures; and (3) project-level by identifying significant project requirements and developing appropriate transportation management plans (TMPs) to manage these requirements (Scriba et al. 2005).

The FHWA has also developed the National Highway Work Zone Safety Program (NHWZSP) to reduce fatal and injury crashes in work zones in order to enhance traffic mobility and safety within work zones (FHWA 2009a). This program is designed to review the standards of traffic control devices, operational features, traffic control plans, and contract specifications to identify and improve work zone management practices. The program consists of four main components: (1) standardization; (2) compliance; (3) evaluation; and (4) implementation (FHWA 2009a). The National Work Zone Safety Information Clearinghouse (NWZSIC) can also be used to retrieve and analyze data on work zone crashes, statistics, laws and regulations, news and events, research, safety products, standards and practices, and training programs (FHWA 2009a).

The Illinois Department of Transportation (IDOT) has developed the Illinois Strategic Highway Safety Plan (IDOT 2011a) that identified work zone safety as a priority area and it seeks to provide a high level of safety for both motorists and construction workers. The plan outlines IDOT guidelines to comply with the FHWA Work Zone Safety and Mobility Rule. The main safety goal of this plan is to achieve a new goal of “Zero Fatalities,” which envisions reducing fatalities on Illinois roads to zero in the long term. In order to achieve this goal, IDOT has developed: (1) significant route location maps; and (2) work zone safety and mobility process flow charts, as shown in A.5 (IDOT 2011a). First, the work zone significance is determined using the significant route location maps that classifies routes into three categories: (1) non-significant; (2) significant – short term (less than 3 days); and (3) significant – long term. The work zone safety and mobility process flow chart, as shown in Figure 2.4, is used to guide the necessary steps to implement the federal work zone safety and mobility rule.

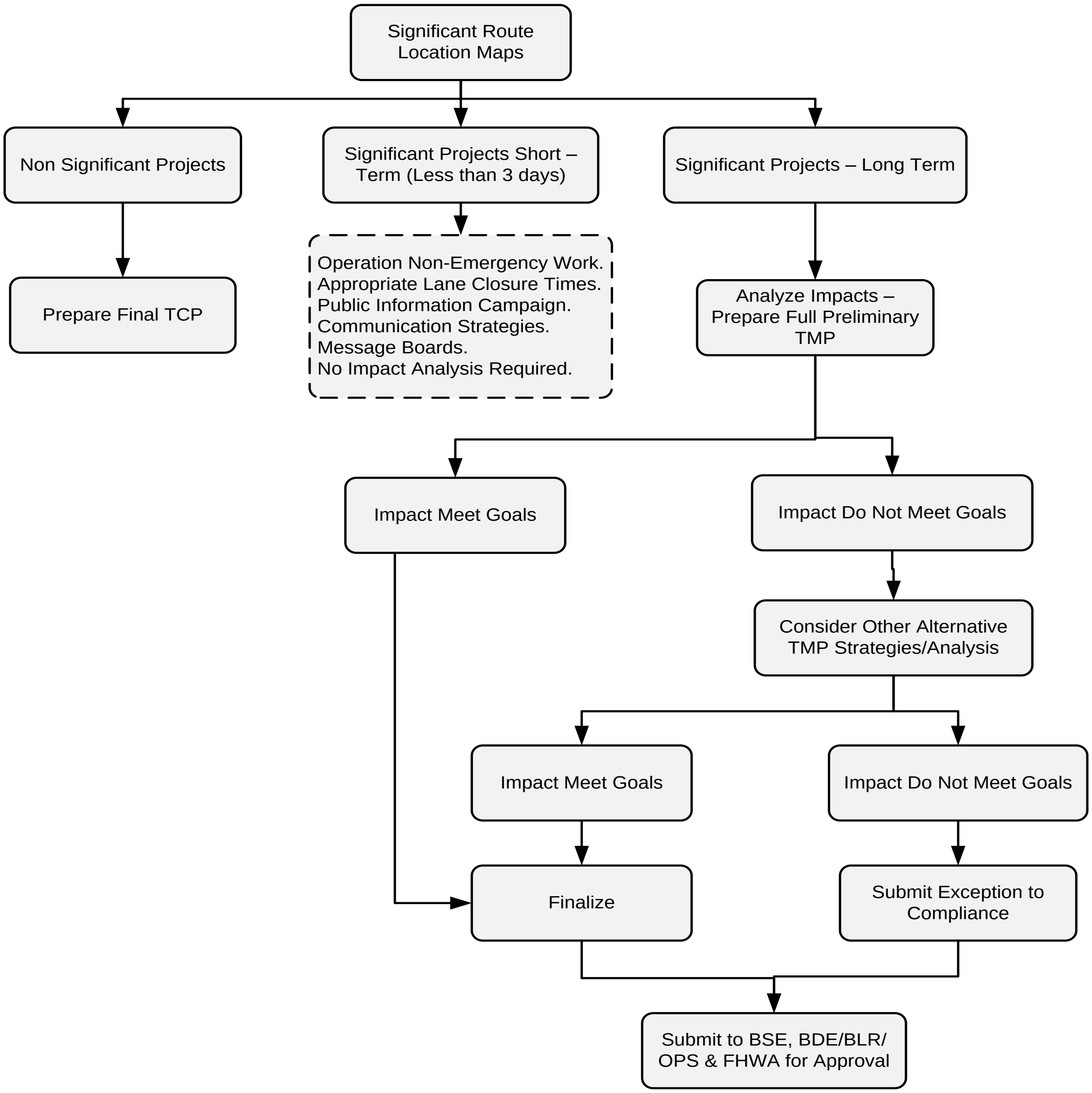

Figure 2.4. Work Zone Safety and Mobility Process-Flow Chart (IDOT 2011a)

For significant long-term projects, impact analysis is required to determine the greater impact that work zones may cause to traffic (FHWA 2009b). The impact analysis should involve the safety and mobility impacts of the construction/maintenance project utilizing hourly volume maps, district knowledge and experience, site reviews, computer simulation programs such as QUEWZ, TSIS-CORSIM, and Quick zone by University of Florida (IDOT 2007). To address the expected impacts, various Transportation

Management Plan (TMP) strategies are developed and the resulting impacts of delays and queuing are evaluated.

The Illinois Strategic Highway Safety Program (IDOT 2011a) also seeks to assess and improve the safety of work zones by requiring the submission of a detailed work zone crash summary report for any fatal work zone crash within 10 days to the Bureau of Safety Engineering. This report analyzes the crash data and includes the following information: (1) summary of the type of construction; (2) description of the traffic control in place at the time of crash; (3) description of the traffic conditions at the time of the crash; (4) description of the contractor’s operations at the time of the crash; (5) description of the weather conditions; (6) pavement conditions, and time of day; (7) description of changes made to the traffic control as a result of the crash; (8) recommendations for change to IDOT standards, and (9) photos of the traffic control throughout the project before and after the crash (IDOT 2011a).

2.4. EFFECTIVENESS OF TRAFFIC CONTROL DEVICES

This section analyzes the feasibility and effectiveness of new and existing work zone safety measures that can enhance work zone safety and mobility on freeways and highways work zones. The analyzed measures include: intrusion alarms alert systems, portable changeable message signs (PCMS), portable speed monitoring displays (PSMD), temporary rumble strips, radar drones, truck mounted attenuators (TMA), mobile barriers, and automated flagger assistance devices (AFAD). The following subsections summarize the main features of each measure and their reported effectiveness in recent research studies.

2.4.1. Intrusion Alarms

Intrusion alarms, such as the SonoBlaster®, are impact-activated safety devices that warn construction workers and errant vehicle drivers simultaneously to help prevent crashes and injuries in work zones, as shown in Figure 2.5. SonoBlaster® can be mounted on typical work zone barricades, cones, drums, delineators, A-frames and other barriers. Upon impact of an errant vehicle, the SonoBlaster's built-in CO2-powered horn blasts at 125 dB to alert workers that their protective zone has been violated, giving them critical reaction time to move out of harm way (SonoBlaster 2011).The system also warns errant drivers in case of an intrusion into a work zone.

2.4.1.1. Features

Intrusion alarms, such as the SonoBlaster®, are impact-activated safety devices that warn construction workers and errant vehicle drivers simultaneously to help prevent crashes and injuries in work zones, as shown in Figure 2.5. SonoBlaster® can be mounted on typical work zone barricades, cones, drums, delineators, A-frames and other barriers. Upon impact of an errant vehicle, the SonoBlaster's built-in CO2-powered horn blasts at 125 dB to alert workers that their protective zone has been violated, giving them critical reaction time to move out of harm way (SonoBlaster 2011). The system also warns errant drivers in case of an intrusion into a work zone.

Figure 2.5. Intrusion Alarm (SonoBlaster® 2011)

In a recent study sponsored by NJDOT, Krupa (2010) evaluated the effectiveness of a “SonoBlaster® Work Zone Intrusion Alarm.” The study concluded that the alarm’s sound is satisfactory during normal traffic conditions and for a distance of 200 ft even if ear protection is worn. In addition, the effectiveness of the alarm system and its sound levels were tested when a roller and other high-noise mechanical equipment, such as jack-hammers, were in use. Based on the results of these tests, the study concluded that the roller operator was able to hear the alarm during equipment operations. However, the study did not reach the same conclusion for operators of other high-noise mechanical equipment such as jack-hammers. The study also reported that the setup procedures could be confusing and that the units were very sensitive and therefore had to be carefully handled, which might cause delays for the setup crews and expose them to traffic hazards. In order to improve effectiveness of the alarm system, the study recommended (1) increasing the alarm’s sound, volume, and duration, (2) making the docking easier, and (3) modifying alarms attachment to the cones to allow for cones stacking. The study concluded that SonoBlaster® equipped cones could be more useful for smaller roads with lower speeds and less traffic. Based on the findings of this study, NJDOT decided not to deploy the tested alarm system because of reported quality control, reliability, and cost issues.

In another recent study, Wang et al. (2011) evaluated the effectiveness of this alarm system using a nationwide survey of DOTs. In this survey, three states reported that they were using or testing the alarm system and six other states reported that they had used or tested them in the past. The survey results also show that 44% of these nine states reported that the alarm system was ineffective, while the remaining 56% did not provide their opinion regarding the effectiveness of the alarm system. In addition, survey respondents reported other operational problems associated with false alarms, maintenance, and installation time.

Kuta (2009) conducted another study to evaluate the feasibility and effectiveness of the intrusion alarm system. A total of 48 sets of the system (1175 units) were distributed to and evaluated by various agencies across the nation as shown in Figure 2.6 and Figure 2.7. The study found the following operational problems to be associated with the SonoBlaster® system: (a) difficulty of storing cones with SonoBlaster® units, (b) length of the system setup and dismantling time, (c) difficulty of arming the unit, (d) difficulty of verifying that the unit was armed, and (e) failure of the alarm sound to alert workers in noisy work zones. The study also provided the following suggestions to improve the system: (1) increase system volume and duration, (2) make system units stackable to facilitate and speed up setup and storage, (3) shorten and clarify setup directions, and (4) make system indicator more visible so that workers can verify that the system is active from a far distance.

Other studies were also conducted by New York and Washington DOTs to evaluate the effectiveness of intrusion alarm systems (Hibbs 1997). Based on the findings of Washington DOT evaluation, the alarm systems were proven user-friendly and easy to set up. On the other hand, the study reported that the devices did not produce a warning loud enough to be heard by workers over existing traffic and construction sounds. New York DOT study reported that 88% of work crews favored the intrusion alarm system and were interested in purchasing it. During field evaluation of that study, errant vehicles set off the intrusion alarms several times, but none of the vehicles entered the work area.

Figure 2.6 Intrusion Alarms Demonstration (Kuta 2009)

Figure 2.7. Intrusion Alarms (Kuta 2009)

2.4.2. Temporary Rumble Strips

2.4.2.1. Features

Temporary rumble strips are devices that generate sounds and vibrations as vehicles pass over them to draw drivers' attention to roadway/work zone conditions. Temporary rumble strips are used over short distances in different patterns for the purpose of providing motorists with increased perception of speed (Fontain and Carlson 2001). The rumble strips consist of intermittent, narrow, and transverse areas of rough-textured or slightly raised road surface extending across travel lanes to alert drivers of uncommon vehicular conditions (Miles and Finley 2007). Rumble strips patterns vary according to several factors, including pavement materials, types of rumble strips, locations of wheel paths relative to rumble strips, and duration of temporary arrangement (Meyer 2000).

2.4.2.2. Effectiveness

Several recent studies evaluated the effectiveness of various types of rumble strips with different configurations. In a recent IDOT sponsored study, El-Rayes et al. (2010) performed field experiments to study the efficiency and effectiveness of using temporary rumble strips prior to and at the edge of work zones as shown in Figure 2.8. Field experiments were conducted on different patterns of three types of temporary rumble strips using three testing vehicles: sedan, cargo van, and 26-foot truck. Sound levels of 189 test configurations were continuously collected as testing vehicles traversed different patterns of the rumble strips. The findings of the experiments confirmed that (1) the three tested types of temporary rumble strips were efficient in terms of installation and removal while the total installation efficiency varied according rumble strips type and the number of strips per set; and (2) the temporary rumble strips were effective in terms of generating auditory stimulus capable of alerting motorists of the approaching work zone.

Figure 2.8. Site of Field Experiments Showing Tested Sets of Temporary Rumble Strips (El-Rayes et al. 2010)

Other research studies evaluated the effectiveness of temporary rumble strips in reducing vehicles speed in enforced work zone areas. These studies proved that temporary rumble strips are effective temporary traffic control device for alerting motorists to reduce their speed (Meyer 2000), (Fontaine and Carlson 2001). Meyer (2000) evaluated the effectiveness of 1/8 in. thick temporary rumble strips versus standardized 1/2 to 3/4-in. asphalt rumble strips at a bridge repair site in Kansas. The reduction in vehicle speeds caused by the temporary rumble strips was then quantified and compared with the speed reduction caused by standard asphalt rumble strips. The study reported that the 1/8 in thick strips were not sufficient to be reliably detected by drivers, however there was a statistically significant reduction in vehicle speeds after the installation of the strips. In a similar study, Fontaine and Carlson (2001) reported that the percentage of passenger cars that exceeded the speed limit in work zones was significantly reduced after the implementation of temporary rumble strips. In another recent study, Wang et al. (2011) evaluated the effectiveness of temporary rumble strips using a nationwide DOTs survey. In this survey, seven states reported that they were using or testing temporary rumble strips and four other states reported that they had used or tested them in the past. The survey results also show that four of these eleven states (36%) reported that temporary rumble strips were ineffective while the remaining seven did not provide their opinion regarding the effectiveness of temporary rumble strips.

2.4.3. Portable Changeable Message Signs (PCMS)

2.4.3.1. Features

Portable Changeable Message Signs (PCMS) are movable traffic control devices that can display a variety of messages to inform motorists about work zone conditions as shown in Figure 2.9. Displayed messages are limited to the size of the sign, which usually consist of three rows eight characters each. PCMS announcements are used to alert drivers and provide advanced warnings of detours, ramp closures, reduced speed limits, and unexpected traffic queues. PCMS can be mounted on either a trailer or work vehicle; and are capable of displaying two or three lines of text, depending on the PCMS size. A PCMS message can use one, two, or, when absolutely necessary, three phases in which to relay its message (ODOT 2006). PCMSs are commonly used to encourage and direct traffic to transition out of one or more closed lanes before the work zone (Wang et al. 2011).

2.4.3.2. Effectiveness

In a recent study, Zech et al. (2008) evaluated the effectiveness of PCMS messages. The study reported that the message “WORK ZONE MAX SPEED 45” led to a reduction in vehicles speed by 3.3 to 6.7 mph. Therefore, it was concluded that properly selected PCMS messages could be effective in reducing the speed of vehicles in the vicinity of highway work zones. Another study (Garber and Patel 1995) recommended using PCMS in short-term work zones and suggested further research for its use in long-term work zones. Garber and Srinivasan (1998) tested the effectiveness of using PCMS with speed radar to automatically display warning messages to speeding drivers. The study reported that the PCMS and radar combination was more effective than traditional work zone traffic control devices in reducing traffic speed. In a recent nationwide survey, 100% of the responding states that used or tested PCMS (26 states) reported that the device was effective in short-term work zones (Wang et al. 2011).

Figure 2.9. Portable Changeable Message Sign (PCMS)

2.4.4. Portable Speed Monitoring Displays (PSMD)

2.4.4.1. <u>Features</u>

Speed monitoring displays are electronic signs activated by radar to display vehicles speed, as shown in Figure 2.9. PSMDs are used to raise drivers' awareness of their speed and remind them to comply with the posted speed limit. PSMDs are also known as "Driver Feedback Signs," "Radar Signs," and "Speed Signs".

Figure 2.10. Portable Speed Monitoring Display (PSMD)

2.4.4.2. <u>Effectiveness</u>

Pesti and McCoy (2001) evaluated the long-term effectiveness of PSMDs by studying the impact of deploying three PSMDs along a 2.7-mile roadway section for a period of five weeks. Based on the findings of these tests, PSMDs were proven effective in lowering speeds, improving uniformity of speeds, and increasing compliance with speed limits. Furthermore, the study reported that significant speed reductions and speed limit compliance were noticed for one week after the removal of the PSMDs. In another study, Fontaine and Carlson (2001) evaluated the effectiveness of PSMDs in a short-term highway work zone and reported that the use of PSMDs was effective in lowering vehicle speeds. In addition, McCoy et al. (1995) tested the impact of using PSMDs and reported that their use caused a reduction in the average traffic speed by 4 to 5 mph.

2.4.5. Radar Drones

2.4.5.1. Features

Radar Drones are small, lightweight, and weatherproof electronic devices that emit radio signals similar to police radar systems. Radar drones can be mounted on work zone vehicles or signs to reduce traffic speed, as shown in Figure 2.11. This device is used in work zones to activate the radar detectors used by drivers in order to reduce their speed and avoid speeding tickets. Radar drones can be effective in reducing work zone traffic speed because (1) many drivers have radar detectors; and/or (2) drivers with radar detectors may travel faster than other drivers (Eckenrode et al. 2007, Hawkins et al. 2000).

Figure 2.11. Radar Drones

2.4.5.2. Effectiveness

Several studies were conducted to analyze the effectiveness of radar drones in reducing vehicle speeds. Eckenroda et al. (2007) analyzed the findings of similar studies conducted between 1986 and 2007. The analysis concluded that radar drones caused a reduction of 5 to 8 mph in the speed of vehicles equipped with radar detectors and a reduction of 2 mph in the mean speed of all vehicles. Meyer et al. (2000) reported that the effectiveness of radar drones is highly dependent on the percentage of drivers having radar detectors. Benekohal et al. (1992) studied the effectiveness of radar drones in Illinois in rural Interstate work zones. The study reported that radar drones were effective in reducing vehicle speeds by 3 to 6 mph for trucks and 3 mph for cars. In a recent national survey of state DOTs (Wang et al. 2011), eight of the 26 participating state DOTs reported that they were using or had previously used radar drones. Four of these eight states reported that they discontinued using radar drones because of their perceived ineffectiveness. On the other hand, Indiana DOT reported that radar drones were effective in getting the attention of drivers with radar detectors.

2.4.6. Truck-Mounted Attenuators (TMA)

2.4.6.1. Features

Truck-mounted attenuators (TMA) are energy-absorbing devices attached to the rear of a shadow trailer or truck to dissipate the energy of a rear-end collision. Shadow vehicles equipped with TMAs should be located ahead of work zones, workers, or equipment to reduce the severity of rear-end crashes caused by errant vehicles. Shadow vehicles are usually equipped with arrow boards, changeable message signs, and/ or high-intensity rotating, flashing, oscillating, or strobe lights located properly ahead of the workers and/or equipment being protected (MUTCD).

2.4.6.2. Effectiveness

In a recent nationwide survey, 100% of the responding states that used or tested TMAs (23 states) reported effectiveness of the device in short-term work zones (Wang et al. 2011). In another study sponsored by Tennessee DOT, Humphreys and Sullivan (1991) evaluated the effectiveness of TMAs and reported that using TMAs saved about $23,000 in crash and reduced damage to the maintenance truck, and that injury rates were higher in maintenance vehicles that were not equipped with TMAs. Other studies investigated the impact of the striping patterns and color at the rear of TMAs on the visibility of TMAs and the ability of drivers to recognize them from safe distances Kamyab and Storm (2010) found that the yellow-green color improved contrast between the orange color of the sign and the orange color of the DOT truck. Hawkins et al. (2000) concluded that fluorescent colors have higher color perception accuracy and recognition distances during daylight hours but not during the night. Bham et al. (2009) indicated that a yellow and black inverted (V) pattern and an orange and white vertical striped pattern were more effective than a fluorescent yellow-green and black inverted (V) pattern or a red and white checkerboard pattern.

2.4.7. Mobile Barriers

2.4.7.1. Features

A mobile barrier is an integrated rigid wall or semi-trailer used in conjunction with a standard tractor to provide safe and mobile work environments for workers in work and maintenance zones, as shown in Figure 2.12 and Figure 2.13. It functions as an extended longitudinal barrier that provides physical and visual barrier between traffic and work zone crews (Wang et al. 2011).

Figure 2.12. Mobile Barrier Trailer (MBT-1) System (Mobile Barriers LLC 2009)

Figure 2.13. Balsi Beam Mobile Barrier System (Wang et al. 2011)

2.4.7.2. Effectiveness

In a recent study, Kamga and Washington (2009) analyzed the effectiveness of the mobile barrier system, MBT-1. It was reported that the system exceeded expectations on the protection of workers from physical injuries caused by errant vehicles because of its ability to absorb crash energy by crushing upon impact and because of its integrated TMAs. In another study, Hallowell et al. (2009) investigated the effectiveness of the mobile barrier system, MBT-1, in work zones in Colorado. The study reported that the MBT-1 system was capable of improving the safety of highway construction and maintenance work zones. Based on the findings of a national survey of state DOTs, Wang et al. (2011) reported that none of the responding states had used the mobile barrier systems because of their high cost, but that they would be interested in using them in the future if they became less costly.

2.4.8. Automated Flagger Assistance Devices (AFAD)

2.4.8.1. Features

Automated flagger assistance devices (AFADs) allow flaggers to be positioned out of the traffic lane and are used to control road users in temporary traffic control zones. These devices are designed to be remotely operated by a single flagger located at one end of the TTC zone or at a central location or by separate flaggers located near each device, as shown in Figure 2.14. AFADs are appropriate for short-term and intermediate-term activities, but may not be used for long-term activities (MUTCD).

Figure 2.14. Automated Flagger Assistance Device (AFAD)

2.4.8.2. Effectiveness

A recent study evaluated the effectiveness of automated flagger assistance devices in Virginia. The study reported that AFADs were successfully deployed by two VDOT area headquarters and were useful in reducing the need for flaggers and minimizing their exposure to hazards (Cottrell 2006).

2.4.9. Radar-Activated Flagger Paddle

Radar-activated flagger paddles consist of a flashing LED flagger paddle that can be activated when the radar detects vehicles exceeding the speed limits. The paddle's red and white LEDs blink alternatively when the radar detects a speeding vehicle. The radar can function only when the stop legend is facing the traffic. The researchers who developed this prototype device recommended further testing to evaluate its effectiveness (Fontaine et al. 2001).

2.5. EFFECTIVENESS AND RISKS OF USING FLAGGERS

2.5.1. Effectiveness of Using Flaggers

A number of research studies have been conducted to evaluate the effectiveness of using flaggers in work zones. For example, El-Rayes et al. (2010a) surveyed IDOT resident engineers and analyzed their assessment of the effectiveness of various TTC devices and methods, including flaggers, in reducing the risk of crash occurrence. The findings of the survey showed that more than 85% of the surveyed IDOT resident engineers reported that using flaggers provides an effectiveness level that ranges from medium to high. In another study, Li and Bai (2006) evaluated the effectiveness of several commonly used TTC methods using a logistic regression technique and various chi-square statistics. The assessed TTC methods included flagger/officer, stop sign/signal, flasher, no passing zone control, and pavement center/edge lines. The findings of the study indicated that flagger, flasher, and pavement center/edge lines were effective in reducing the probability of fatalities when severe crashes occurred. In addition, using these devices could prevent various common human errors such as “disregarded traffic control,” “inattentive driving,” “followed too closely,” and “exceeded speed limit” from causing severe crashes. Results of the study also indicated that using a flagger/officer in a work zone could reduce the probability of a severe crash being caused by “disregarded traffic control” human errors by 54%.

Another study reported that flaggers are most effective on two-lane, two-way rural highways and urban arterials, where they had the least competition for drivers’ attention (Richards 1985). The same study also reported that flaggers were well suited for short-duration applications (less than one day) and for intermittent use in long-duration work zones. Garber and Woo (1990) conducted another study and reported that the most effective combination of traffic control devices for work zones on multi-lane highways were cones, arrow boards, and flaggers, while in work zones on urban two-lane highways, cones and flaggers, as well as static signs and flaggers, were the most effective combination.

2.5.2. Risk of Using Flaggers

Owing to the nature of their duties, which require them to be in close proximity to open traffic lanes and often without the protection of physical barriers, flaggers are often exposed to hazardous conditions and to the risk of injuries or fatalities (See et al. 2009). Pratt et al. (2001) reported that two-thirds of the injuries to pedestrian workers occurred from vehicles intruding into marked workspaces and striking workers or flaggers. Mohan and Zech (2008) analyzed work zone crashes that caused 36 fatalities and 3,055 severe injuries in New York State from 1990 to 2001. The study found that 86% of these fatalities and 70% of these severe injuries were caused by five types work zone crashes: (1) work space intrusion, (2) worker struck by vehicle inside workspace, (3) flagger struck by vehicle, (4) worker struck by vehicle entering/exiting work space, and (5) construction equipment struck by vehicle inside workspace. Another study also reported that construction workers were twice as likely to be killed by a motor vehicle as the average worker and that flaggers account for half of pedestrian accidents (Ore and Fosbroke 1997).

2.6. USE OF SPOTTERS IN WORK ZONES

A spotter is a trained worker whose sole duty is to monitor traffic and warn workers of errant drivers or other hazards using an effective warning device such as a whistle or air horn (WSDOT 2009). A spotter does not control traffic or use a traffic regulator paddle, but instead uses a warning sounding device. The location of the spotter must be away from unnecessary danger. The following section presents spotter definitions and tasks from some of the states that deploy spotters.

Several state DOTs, such as those in Washington and Oregon, recently began recommending the use of spotters and/or of flaggers to warn workers of errant drivers in multi-lane highway work zones with speed limits greater than 40 mph (WSDOT 2012; ODOT 2011). The following sections summarize available definitions of spotters and their tasks that are provided by a number of state DOTs.

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2.6.1. Virginia DOT

Virginia DOT (VDOT) defines a TTC spotter as a certified flagger whose primary function is to monitor traffic conditions and warn co-workers who are performing tasks such as installing or removing TTC devices, traffic counting devices and removing debris from the roadway of oncoming traffic. A TTC Spotter may stop or slow traffic using a red flag and the correct flagger procedures. Qualifications, clothing requirements, and hand signaling procedures for TTC spotters shall be the same as for flaggers. The hand signaling device for a TTC spotter shall be a red flag or a fluorescent orange/red flag a minimum of 24 inches square fastened to a staff that is approximately 36 inches in length. The location of the TTC spotter shall be highly visible to oncoming traffic and the TTC spotter shall stop traffic if necessary when co-workers are installing or removing devices (VDOT 2011).

2.6.2. Michigan

According to Michigan DOT (MDOT), spotters (1) instruct truck drivers when working near other equipment and brief them on procedures for leaving the project area and re-entering the traffic stream and (2) are used solely to alert workers or watch traffic and alert workers of the approach of an errant vehicle. A spotter does not use a traffic regulator paddle, but instead uses a warning sounding device which emits sounds that are different from conventional vehicle horns. The device should be identified to on-site workers so they can take necessary actions whenever they recognize the sound. Michigan DOT recommends using spotters only when the risks to workers exceed those of the spotter. It is also recommended that spotter locations be shown on the temporary traffic control plan (MDOT 2010).

2.6.3. Oregon

Oregon DOT (ODOT) defines a spotter in its TTC handbook for operations of three days or less as “an employee whose sole duty is to provide immediate warning of approaching vehicles, equipment, or other hazards to co-workers" (ODOT 2011). ODOT specifies spotter roles and responsibilities and requires a spotter to: (a) focus only on the spotter duties; (b) be within sight or sound of the employee(s) being protected; (c) choose a location that provides optimum sight distance and safety; (d) know the "Alert Call" or communication plan; (e) be on alert to sound the alarm; (f) be in place before the operation begins; and (g) confirm that all affected parties understand the action plan.

ODOT also specifies the following key components in developing and implementing an effective Spotter training and performance program:

1. Action Plan – A site or task specific plan along with a hazard assessment for using a spotter must be completed before a spotter can be used. All affected parties must understand the action plan before starting work.

2. When to Use- The need for spotters can be dictated by one or more factors for a given operation or task, including location of task, type of highway, vertical or horizontal alignment, traffic volume or speed, construction or maintenance activity, traffic controls used, added safety control, and vegetation, trees, roadway geometrics or other conditions that might restrict sight distance or safety of an employee.

3. Location of Spotter – A spotter shall be within visual and verbal contact of employee(s) that are being protected. If visual contact cannot be made with workers, use an air-horn, two-way radio, or other warning device to alert workers of an eminent unsafe condition.

4. “Alert Call” and Escape Route – The “Alert Call” (made by voice or mechanical means) needs to be clearly heard above all surrounding noise levels when it appears an unplanned safety problem, errant motorist, equipment or other hazard is intruding into the zone of protection. The “Alert Call” shall be understood and agreed upon by all work party members prior to beginning work. A predetermined escape route for both the spotter and the protected employee(s) shall be established prior to beginning work and agreed upon by all affected parties.

5. Commencement of Work – The spotter shall be in place and prepared to issue alerts before work begins.

6. Training – All affected employees shall understand the roles and responsibilities of a spotter.

ODOT also recommends considering the use of a spotter when:

- Workers have their backs to traffic or other hazards.
- Workers and heavy equipment are working in the same area concurrently.
- Performing work where adequate gaps in traffic allow work to be done in a live travel lane.
- Work encroaches into the roadway, but maintains a minimum 10 ft travel lane.
- Sight distances are limited by vegetation or other conditions.
- Posted speeds are 45 mph or higher.

2.6.4. Wisconsin

Wisconsin DOT (WISDOT) defines the spotter as an emergency personnel assigned to monitor approaching traffic and activate an emergency signal if the actions of a motorist do not conform to established traffic control measures in place at the incident scene (WISDOT 2008).

2.6.5. Washington

Washington DOT (WSDOT 2012) requires the use of a spotter on a very short duration lane closure to provide advance warning to traffic approaching very short duration work zones on freeways and high speed multi-lane highways as shown on Temporary Control Plan (TCP 19A) when working in a live lane TCP 19a classifies the use of spotters as (a) allowed, (b) required, or (c) not recommended, depending on traffic and hazard conditions:

Using a spotter is allowed in work zones with low impact levels (i.e., low traffic speed and volume and minimum levels of warning, protection, and hazards). In these work zones, a work vehicle with warning beacon and personal protective equipment may be adequate.

Using a spotter is required in work zones with moderate impact levels (i.e., low or high traffic speed with low to moderate volumes). A moderate level of warning and protection should be considered in these types of work zones, such as spotters, cones or Portable Changeable Message Sign (PCMS), in addition to the devices mentioned in the low impact scenario.

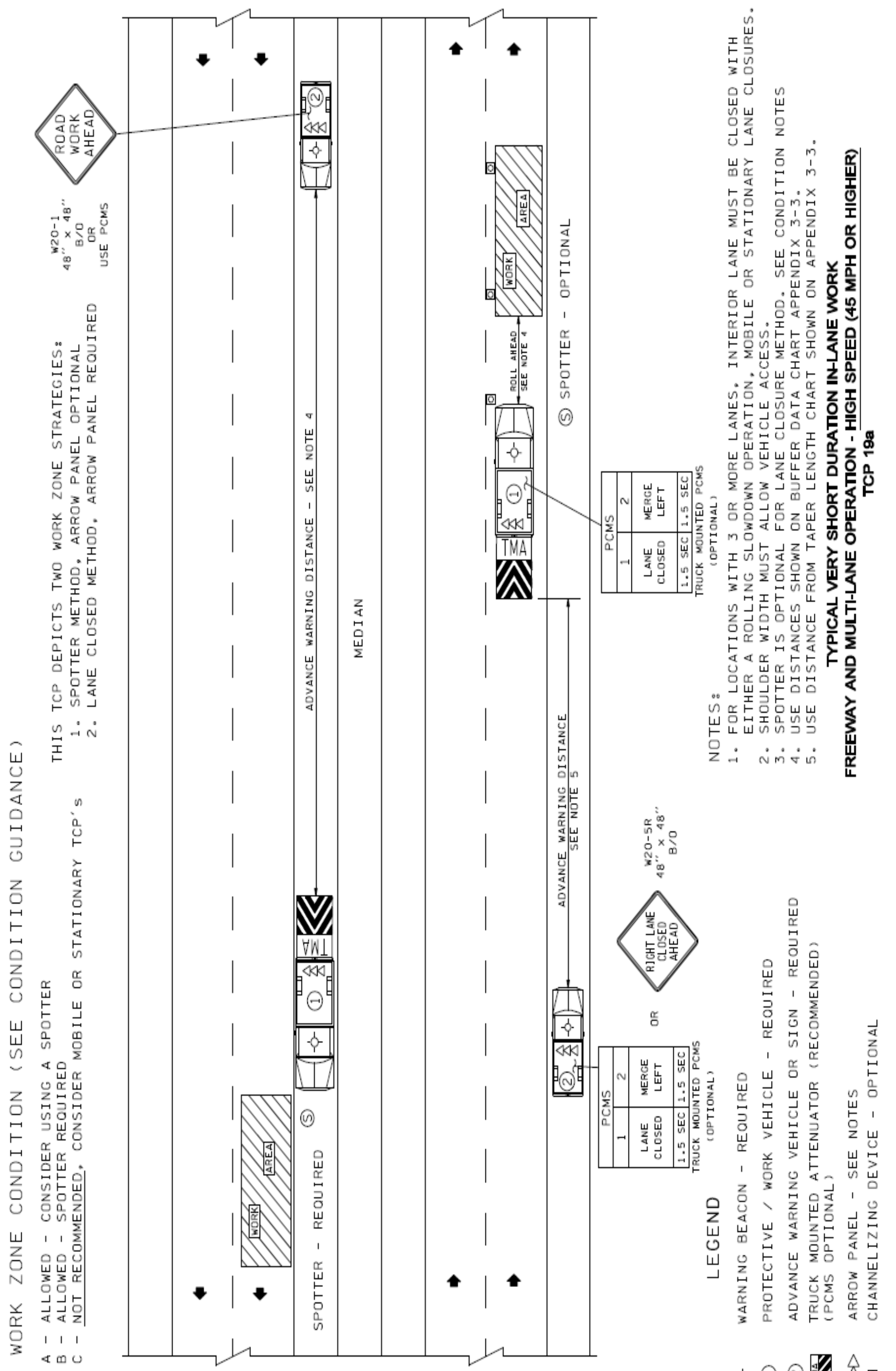

Figure 2.15. Typical Very Short-Duration in-Lane Work Freeway and Multi-Lane Operation at Speeds of 45 mph or Higher (WSDOT 2012)

2.7. IMPACT OF WORK ZONE LAYOUT PARAMETERS ON MOBILITY AND COST

Work zones require lane closures during construction and accordingly they cause traffic congestions and delays resulting in increased road user delay, traffic incidents, and vehicle emissions (Borchardt et al. 2009, Du and Chien 2014). To minimize the aforementioned negative impacts of work zones, their layout needs to be designed to deploy traffic-delay mitigating measures such as reducing the length of work zone segments, using the shoulder, and working during low traffic hours (Chien 2014, Jiang and Adeli 2003, McCoy 1998). Despite the benefits that can be gained from these measures, they often require additional construction and work zone setup costs. For example, reducing the length of work zone reduces the queue length of traffic, however it increases the number of work zone segments and their setup and traffic control costs (Chien and Schonfeld 2001, Cohen et al. 2003, McCoy and Mennenga 1998; Jiang and Adeli 2003; Zhu et al. 2009). Similarly, the shoulder can be temporarily used to increase the live lane width or to provide an extra lane to mitigate traffic congestion, however this requires additional cost and time to prepare the shoulder for regular traffic (Du and Chein 2014). Moreover, working during low traffic hours such as nighttime often reduces traffic delays, however it increases cost due to the higher overtime premiums of labor and/or the required lighting equipment for nighttime construction (Tang and Chien 2008, Chien et al 2002). Accordingly, these tradeoffs between reducing work zone delays and minimizing construction costs needs to be carefully analyzed and optimized to establish an optimal balance between these two critical and conflicting objectives.

A number of studies analyzed the impact of various work zone layout parameters on traffic delays and cost. For example, the impact of work zone segment length and lane closure on construction and road user costs was analyzed by McCoy and Mennenga (1998). The impact of highway work zone schedule on both agency and user costs was studied by Tang and Chien (2008) while considering varying traffic times, maintenance cost, and crew cost. The impact of lane width, lateral clearance between work area and live lanes, and shoulder width on the capacity of work zone was studied by Benekohal et al. (2003 and 2010). The impact of the temporary use of shoulders on traffic delays was analyzed by a number of studies (Boyles and Waller 2007; Elefteriadou et al. 2007; MDSHA 2008; Du and Chein 2014).

Other studies developed analytical models, simulation programs and optimization models to quantify and minimize traffic delays and cost. For example, analytical models were developed to estimate the impact of work zone parameters on work zone capacity and traffic delays (Jiang and Adeli 2003, Borchardt 2009, Benekohal et al. 2010). Simulation programs were also developed to determine the freeway work zone capacity such as QUEWZ (Memmott and Dudek 1984) and Quick Zone delay estimation program (Mitretek, 2005). In addition, a number of optimization models were developed to minimize the total cost of crash, agency and road user costs by identifying optimal work parameters zone parameters such as length, starting time, work schedule, and temporary traffic control devices (McCoy 1998; Chien et al. 2002; Jiang and Adeli 2003; El-Rayes and Kandil 2005; Elghamraway 2011; Chen and Schonfeld 2001; Chen et al. 2005; Yang et al. 2009; Meng and Weng 2011, Du and Chien 2014, Jian and Adeli 2003, and Kandil et al 2010).

CHAPTER 3
WORK ZONE FIELD STUDIES

3.1. INTRODUCTION

In order to evaluate current layout design, TTC measures and safety devices that are used in highways work zones, seven highway construction work zones were studied in May through July of 2012 and in July 2013. During these field studies, data were gathered on (1) the type of construction operations performed in the work zone, (2) layout of the work zone and temporary traffic control measures used in the work zone, (3) impact and effectiveness of using flaggers, if any, and (4) impacts of measures of controlling access and egress in the visited work zones. The following sections present a brief description of the data gathered during seven of these field studies.

3.2. INTERSTATE HIGHWAY 57, CHAMPAIGN, ILLINOIS

This construction project, located on the southbound of Interstate highway 57 between Olympian Drive in Champaign and 2 miles south of Thomasboro, Illinois, was visited on May 18, 2012. The operations observed in the highway construction project included removing existing pavement, paving, and rolling operations, as shown in Figure 3.1, Figure 3.2, Figure 3.3, and Figure 3.4, respectively. The flagger was holding a STOP/SLOW paddle to control the traffic, as shown in Figure 3.5. The work zone also had a flagger warning sign located ahead of the flagger to warn oncoming traffic, as shown in Figure 3.6. In addition, other temporary traffic control devices were used, including (1) direction indicator barricades, as shown in Figure 3.7, (2) arrow boards, as shown in Figure 3.7, and (3) drums, as shown in , Figure 3.9, Figure 3.10, and

Figure 3.11. Furthermore, the use and effectiveness of flaggers in this type of work zone has been discussed with the project’s flaggers and resident engineer

Figure 3.1. Pavement Removal Operations on I-57

Figure 3.2. Paving Operations on I-57

Figure 3.3. Roller Operations and Flagger to Control the Traffic

Figure 3.4. Flagger Location

Figure 3.5. Flagger Holding a SLOW Paddle

Figure 3.6. Flagger Warning Sign

Figure 3.7. Direction Indicator Barricades and Arrow Board

Figure 3.8. Lane Closure Using Drums

Figure 3.9. Speed Limit Sign at The Beginning of the Work Zone

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Figure 3.10. Drums and Opening for Exit Ramp

Figure 3.11. Speed Limit Sign, Direction Indicator Barricades, and Drums

3.3. INTERSTATE HIGHWAY 474, ILLINOIS

This bridge construction project, located on highway I-474 over the Illinois River in Peoria, IL, was visited on May 18th, 2012. The observed construction operations on this bridge repair project included installation of new joints for the steel bridge and steel repair. The layout of the work zone and its Temporary Traffic Control (TTC) plan redirected the traffic away from the side the highway of the bridge under repair to the other side of the highway (crossover) using temporary concrete barriers between the two directions on the other bridge as shown in Figure 3.12. This work zone layout was also able to provide complete separation between the work zone and the open traffic on the other side of the highway. Accordingly, this work zone did not deploy flaggers at the current stage of construction since there was no contact between the work zone and the direct traffic.

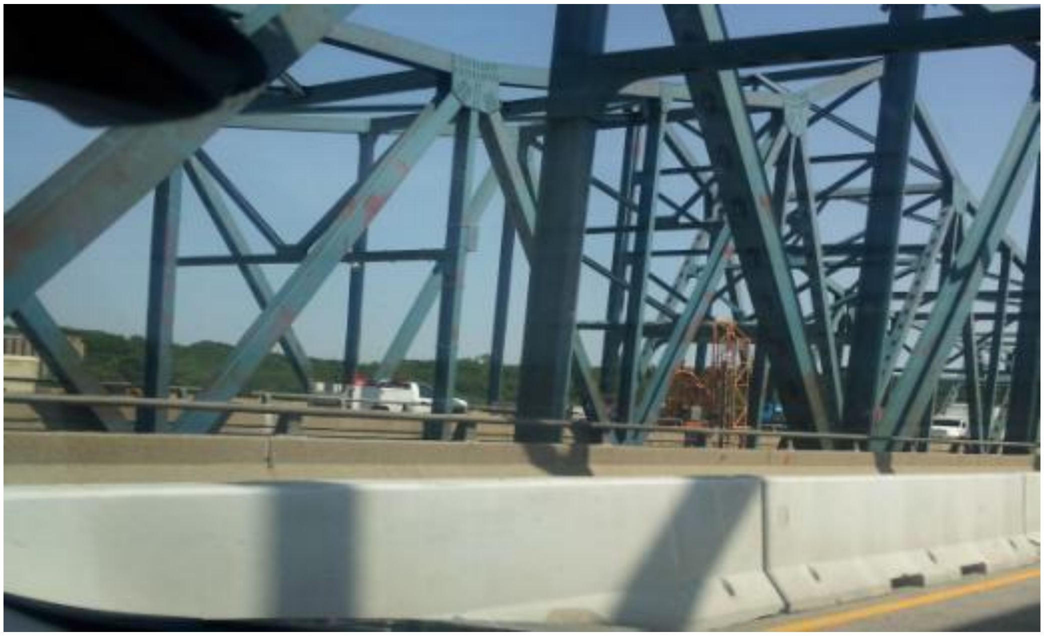


Figure 3.12. Temporary Concrete Barriers between the Open Traffic Lanes on One Side of the Bridge and the Work Zone on the Other Side

3.4. INTERSTATE155, MORTON, ILLINOIS

This construction project, located on Interstate-155 in Morton, Illinois, was visited on July 11, 2012. Milling operations was observed for the replacement of the drainage system underneath the road shoulder as shown in Figure 3.13 and Figure 3.14. The main types of traffic control measures that were used on the construction site were: direction indicator barricades, drums, speed indicators, arrow boards, flagger warning signs, and flaggers, as shown in Figure 3.15 to Figure 3.19.

In this work zone, a flagger was deployed at the edge of the live lane to control traffic, as shown in Figure 3.18. . Impact of using flaggers in directing traffic and controlling access and egress were quantified by measuring the speed of traffic and length of queue. A speed gun has been used to measure traffic speeds, as shown in Figure 3.20. The vehicles monitored were traveling at or below the posted speed limit of 45 mph.

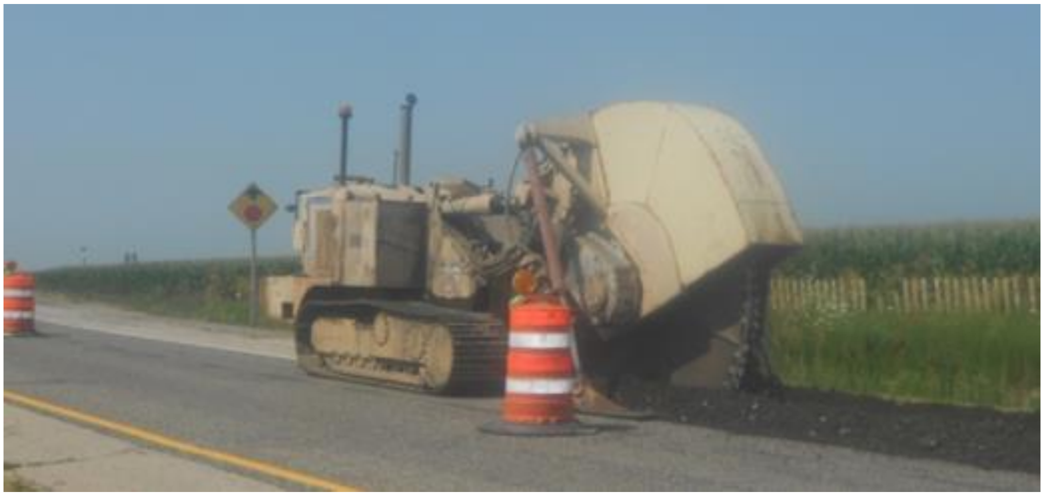


Figure 3.13. Milling Operations Using Trench Cutter

Figure 3.14. Horizontal Milling Operations Using Trench Cutter

Figure 3.15. Speed Indicator and Traffic Drums

Figure 3.16. Direction Indicator Barricades and Arrow Board

Figure 3.17. Traffic Drums

Figure 3.18. Traffic Control Using Traffic Drums and Flagger

Figure 3.19. Flagger Warning Sign Ahead of Flagger Location

Figure 3.20. Using Speed Gun to Measure Traffic Speed

3.5. INTERSTATE HIGHWAY 57, NEAR EFFINGHAM, ILLINOIS

This construction site, located on Interstate-57 near Effingham and Neoga, Illinois, was visited on July 13, 2012. The construction included resurfacing and paving of the highway road. The traffic control devices used on this site included direction indicator barricades, cones, drums, flagger and flagger signs, as shown in Figure 3.21 through Figure 3.25.

Figure 3.21. Live and Work Zone Lanes

Figure 3.22. Work Zone Rolling Operation and Lane Closure Using Cones

Figure 3.23. Rolling Operation, Traffic Drums and Cones

Figure 3.24. Flagger Controlling Traffic at the Edge of Live Lane

Figure 3.25. Rolling Operation in Work Zone and Flagger Controlling Speed on Live Lane

3.6. INTERSTATE HIGHWAY-255, EAST ST. LOUIS, ILLINOIS

This construction project, located on the southbound lanes of Interstate 255 near I-64 in East Saint Louis, Illinois was visited on July 16, 2012. The project involved constructing a large bridge across the Mississippi River and repaving parts of the highway in the nearby interchanges and highway segments. The general project, including several work zones for repairing and reconstructing existing highways, ramps, and bridges. A flagger was deployed to control traffic and guide the trucks entering and exiting the work zone, as shown in Figure 3.26 and Figure 3.27. The flagger was observed completely stopping the traffic on the highway for the vehicles to access the work zones. The speed and delay of traffic were monitored and measured at the access and egress points while the flagger was controlling the traffic.

Figure 3.26. Controlling Traffic at the Edge of Live Lane

Figure 3.27. Two-lane Closure Using Cones and Flagger to Slow the Traffic

3.7. INTERSTATE HIGHWAY-57, CHAMPAIGN, ILLINOIS

This construction project, located in the southbound lane of interstate highway Interstate-57 near West Olympian Drive in Champaign, Illinois, was visited on July 8, 2013. The observed construction operations included (1) the installation of temporary concrete barriers for the work zone and (2) cutting concrete pavement using diamond-blade saw. The following TTC measures were used: (1) a flagger, (2) TTC signs such as lane closure, flagger ahead, and speed limit, and (3) drums, cones, direction indicator barricades, and arrow board, as shown in Figure 3.28 and Figure 3.30. There was no lateral clearance between the work area and the edge of work zone which caused the traffic to excessively slow down the speed below the posted speed limit. A flagger was deployed during the installation of the temporary concrete barriers to slow down traffic and protect workers. A predetermined escape route, allowing the flagger to jump over the barrier and use it as physical protection against errant drivers or other traffic hazards, was established as shown in Figure 3.29. During the field study, the field data was collected about (a) the average time required for the flagger to escape from the live traffic lane, which ranged between 3 and 5 seconds, (b) traffic speed, which ranged between an average of 30 mph at the location of the flagger and 38 mph at the start of the work zone lane closure; therefore indicating that traffic speed was excessively reduced below the 45 mph speed limit because of the flagger, and (c) noise levels generated by construction equipment and an intrusion alarm device that was tested by the researcher, as shown in Table 3.1. The intrusion alarm was manually activated 60 ft. and 120 ft. away from two types of construction equipment (concrete saw and a truck-mounted generator). The sound level was recorded at the location of the two pieces of equipment using a sound meter. The intrusion alarm could be heard when it was activated from a distance of 60 ft. and 120 ft. away from the truck-mounted generator, but was barely audible when activated from a distance of 60 ft. and could not heard at all at a distance of 120 ft. away from the concrete saw.

Table 3.1. Summary of Sound Measurements in dB in Experiment

Distance	Truck-Mounted Generator	Concrete Saw
Noise Before Alarm	85	100-105
Alarm at 60 ft.	105	105
Alarm at 120 ft.	92	105

Figure 3.28. TTC Devices Including Speed Limit Signs, Direction Indicator Barricades, and Drums

Figure 3.29 Installing Temporary Concrete Barriers While Flagger Slows Down the Traffic

Figure 3.30 Flagger Signs and Direction Indicator Barricades

3.8. ILLINOIS TOLLWAY (I-90) BETWEEN ELGIN AND ROCKFORD, ILLINOIS

This construction project, extending 37 miles on Jane Addams Memorial Illinois Tollway (I-90) between Elgin and Rockford, Illinois, was visited on July 24, 2013. The layout of the work zone and its TTC signs followed the MUTCD, including flagger signs, speed limit signs, and drums. During the field study, it was observed and studied several flagger operations and construction activities, including the removal of existing pavement and paving operations. A flagger holding a STOP/SLOW paddle was located at the work zone entrance/exit, 2 to 3 ft. away from the edge of the highway ramp. The flagger monitored traffic, guided trucks entering and exiting the work zone, and alerted workers using hand signals and slowed traffic with the SLOW paddle and used hand signals to alert the workers of trucks exiting the work zone, as shown Figure 3.31. Flagger operations at the access and egress of the work zone were videotaped, and traffic speed was measured to study the effect of flagger operations on traffic mobility. Analysis of the recorded videotapes and traffic speed showed that trucks entering the work zone slowed down the traffic. However, trucks were allowed to exit the work zone only when there was light or no traffic and, accordingly, they did not cause traffic delays, as shown in Figure 3.32.

Figure 3.31. Truck Exits from Work Zone

Figure 3.32 Flagger Slows Down Traffic and Guides Trucks to Enter Work Zone

3.9. MEETINGS WITH RESIDENT ENGINEERS

Two meetings were conducted during the site visits and field studies: (1) a meeting with IDOT engineers in District 7, Effingham, Illinois and (2) a meeting with IDOT engineers in District 8, East St. Louis, Illinois. The purpose of these meetings was to gather feedback from IDOT resident engineers on the effectiveness, safety, and risks of using flaggers and spotters in these types of work zones and to discuss alternative means.

The meetings included guided questions and open discussions aimed at building consensus and obtaining additional comments that were not part of the structured surveys.

3.9.1. Meeting with Engineers, District 7, Effingham, Illinois

Meetings with IDOT resident engineers and other engineers in District 7 were held to gather feedback on the following topics: (1) the safety, need, effectiveness, and limitations of flaggers and (2) the feasibility of replacing flaggers with spotters and/or other measures that can support flaggers and work zones.

3.9.2. Meeting with Engineers, District 8, East St. Louis, Illinois

This meeting held with District 8 engineers and managers on the Mississippi River Bridge Project which connects Illinois and Missouri across the Mississippi River. Feedback and comments were gathered from participating engineers on the need for flaggers, limitations of flaggers, nighttime work, spotters, radar drones, and automated flaggers to increase work zone safety.

CHAPTER 4
WORK ZONE CRASH DATA ANALYSIS

4.1. INTRODUCTION

This chapter presents the findings of a comprehensive analysis of work zone crashes in Illinois during a fourteen-year period, from 1996 to 2009. The objectives of this analysis were (1) to study the frequency and severity of work zone crashes on Illinois expressways and freeways and (2) to investigate the probable causes and factors contributing to work zone crashes. Two main research tasks were performed to accomplish these objectives: (a) data and reports on work zone crashes on Illinois highways were collected from available resources and (b) a comprehensive statistical analysis was conducted to study the frequency, severity, and other characteristics of injury and fatal work zone crashes in Illinois.

4.2. DATA COLLECTION

This research task focused on gathering and fusing the latest data and reports on work zone crashes from all available sources and all types of roads and highways in Illinois for a fourteen-year period (1996 to 2009). The sources of collected data include (1) the National Highway Traffic Safety Administration (NHTSA) that contains data on approximately 400,000 records of all types of Illinois crashes per year and provides a wide range of data for each recorded crash, including crash severity, number of fatalities and injuries, work zone type, traffic volume (AADT), road classification, used traffic control measure, time and day, light conditions, and weather data; and (2) police reports that provide additional data on work zone configuration, flagger and spotter usage, work zone delays and queues, and major delay/queue contributing factors.

4.2.1. NHTSA Data

The latest available data from the NHTSA contained 28,852 crashes on expressway and freeway work zones that caused 148 fatal crashes, 7,087 injury crashes, and 21,617 property damage crashes during a fourteen years period from 1996 to 2009, as shown in

Table 4.1. The composition of Illinois work zone crashes for the years 1996-2009 is presented in Figure 4.1. It illustrates that the Property Damage Only (PDO) crashes are 21,617 crashes and represent 75% of the total number of crashes. The annual number of fatal and injury work zone crashes over the fourteen year period (1996-2009) is presented in Figure 4.2 and Figure 4.3, respectively. It clearly shows an increasing trend starting at (2000) reaching a peak in (2004), then the annual number of work zone crashes slightly decreases and fluctuated over the following five years (2005 to 2009). The total number of injury crashes has fluctuated from 350 to less than 700 annual crashes over the analyzed period as shown in Figure 4.2.

Table 4.1. Work Zone Crashes on Illinois Expressways and Freeways (1996-2009)

Year	Fatal Crashes	Injury Crashes	Property Damage	Total number of crashes	Number of Fatalities	Number of Injuries
1996	*5*	*492*	*700*	*1197*	*7*	*780*
1997	*7*	*363*	*612*	*982*	*8*	*555*
1998	*6*	*548*	*960*	*1514*	*6*	*886*
1999	*5*	*676*	*1203*	*1884*	*5*	*1012*
2000	*10*	*446*	*899*	*1355*	*13*	*648*
2001	*12*	*511*	*1021*	*1544*	*14*	*704*
2002	*15*	*453*	*872*	*1340*	*16*	*728*
2003	*16*	*449*	*847*	*1312*	*25*	*737*
2004	*17*	*349*	*880*	*1246*	*24*	*553*
2005	*13*	*563*	*2429*	*3005*	*16*	*831*
2006	*14*	*677*	*3359*	*4050*	*20*	*982*
2007	*6*	*492*	*2668*	*3166*	*7*	*670*
2008	*13*	*515*	*2879*	*3407*	*13*	*742*
2009	*9*	*553*	*2288*	*2850*	*9*	*806*
Total	***148***	***7,087***	***21,617***	***28,852***	***183***	***10,634***

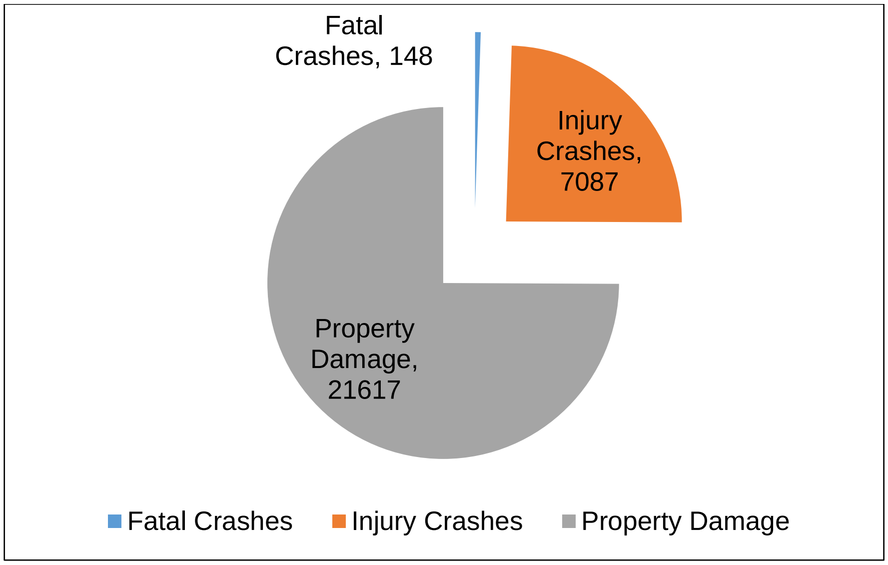


Figure 4.1. Overall Composition of Work Zone Crashes on Illinois Expressways and Freeways (1996-2009)

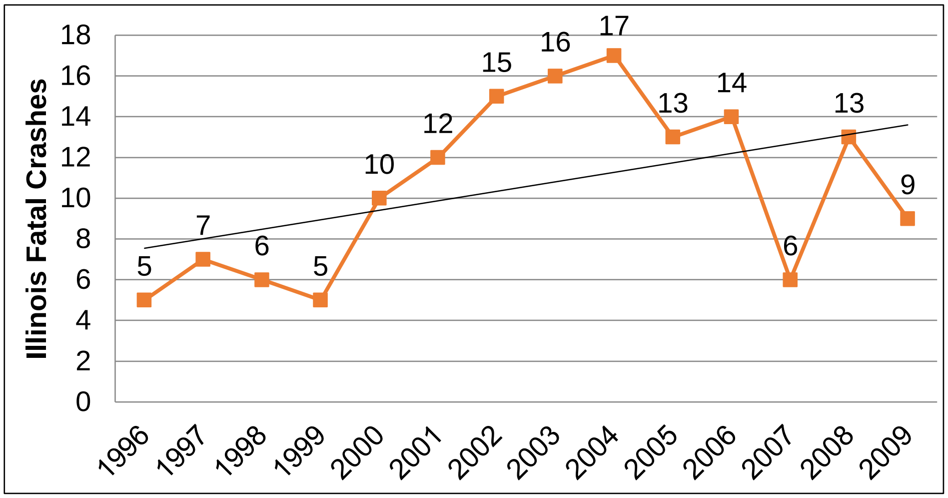


Figure 4.2. Fatal Work Zone Crashes on Illinois Expressways and Freeways (1996-2009)

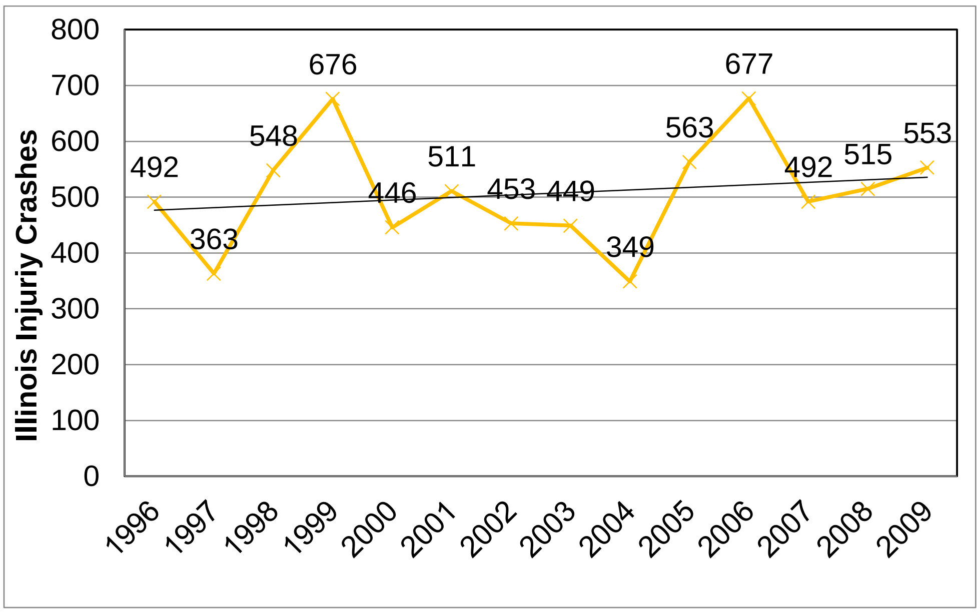


Figure 4.3. Injury Work Zone Crashes on Illinois Expressways and Freeways (1996-2009)

The collection and aggregation of work zone crash data are presented in Appendix A; the findings of the data analysis are described in the following sections.

4.2.2. Police Reports on Fatal Crashes

The second source of data in this study was Illinois police reports on fatal work zone crash flagger/policeman related crashes. These police reports were collected from IDOT and were analyzed to identify and incorporate any additional information on crash circumstances that are not available in NHTSA files. A sample police crash report is shown in Appendix A and Figure A.3.

4.3. DATA ANALYSIS

The following sections summarize the findings of a statistical analysis that was conducted to study the impact of the identified variables listed in Table A.5 in Appendix A -on the frequency of fatal and injury work zone crashes.

4.3.1. Road Data Road Condition (RD_CON1)

The impact of the type of work zone on the frequency of fatal and injury crashes in Illinois highways is shown in Figure 4.4. The work zone variable in this analysis is classified into four types: construction zone, maintenance zone, utility work zone, and unknown work zone. The results show clearly that construction zones were the most dominant type of work zone crashes because they accounted for 88% of fatal crashes and 95% of injury crashes.

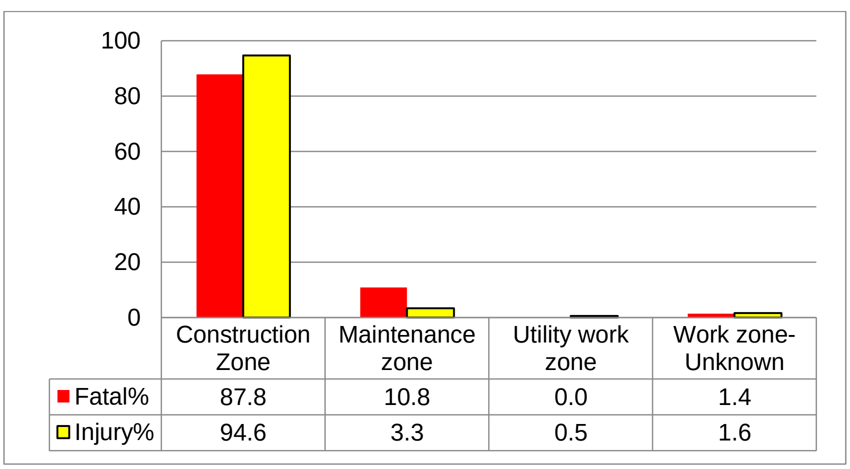
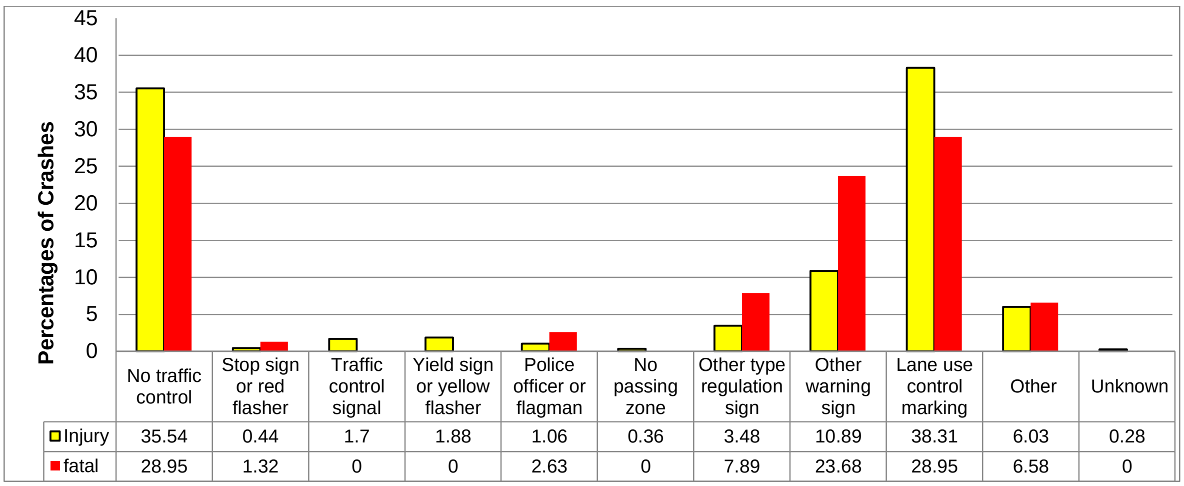


Figure 4.4. Impact of the Type of Work Zone on the Frequency of Fatal and Injury Crashes

4.3.2. Road Data Traffic Control (TRA_CON1)

Figure 4.5 shows the impact of utilizing various traffic control devices on the frequency of fatal and injury work zone crashes on Illinois highways. The results show that 29% of fatal work zone crashes and 35.6% of injury work zone crashes had no traffic control. The results also indicate that the presence of a police officer or flagger in a work zone is an effective traffic control measure because only 2.6% of the fatal crashes and 1.1% of the injury crashes were reported in the presence of a police officer or flagger, as shown in Figure 4.5.

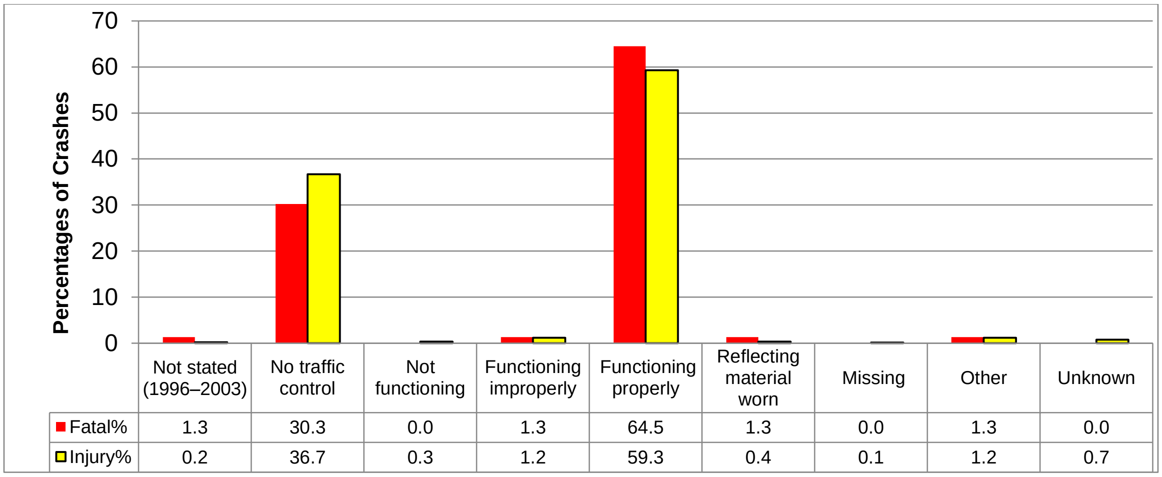


	No traffic control	Stop sign or red flasher	Traffic control signal	Yield sign or yellow flasher	Police officer or flagman	No passing zone	Other type regulation sign	Other warning sign	Lane use control marking	Other	Unknown
Injury	35.54	0.44	1.7	1.88	1.06	0.36	3.48	10.89	38.31	6.03	0.28
fatal	28.95	1.32	0	0	2.63	0	7.89	23.68	28.95	6.58	0

Figure 4.5. Impact of Traffic Control on the Frequency of Fatal and Injury Crashes

4.3.3. Road Data Traffic Function (TRA_FUN1)

Figure 4.6 shows the impact of traffic control functionality on the frequency of fatal and injury crashes in Illinois highways. The results show that 64.5% of fatal crashes and 59.3% of injury crashes occurred in work zones with properly functioning traffic control devices.

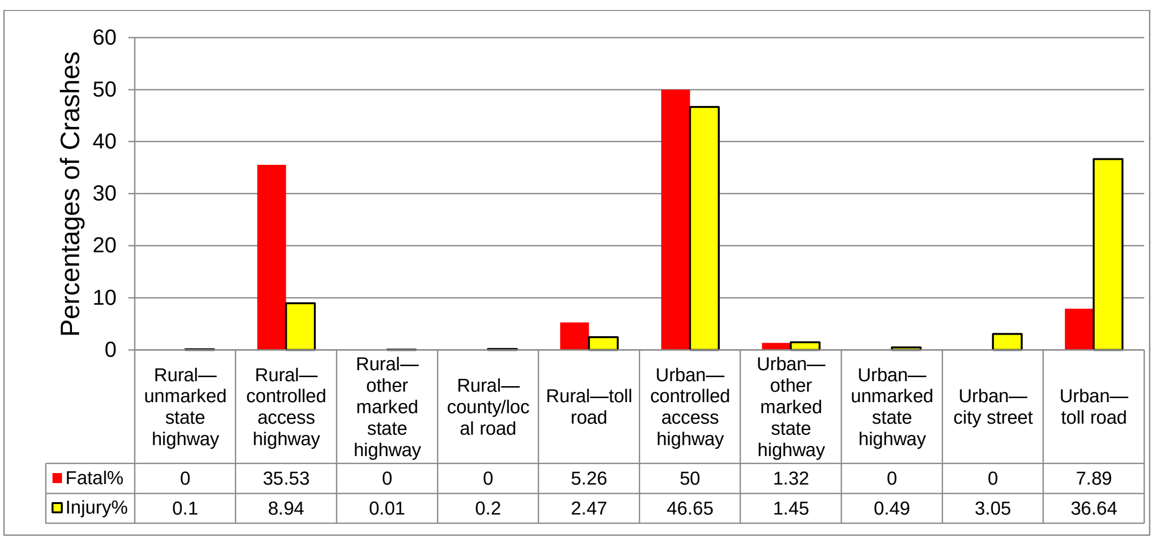


	Not stated (1996–2003)	No traffic control	Not functioning	Functioning improperly	Functioning properly	Reflecting material worn	Missing	Other	Unknown
Fatal%	1.3	30.3	0.0	1.3	64.5	1.3	0.0	1.3	0.0
Injury%	0.2	36.7	0.3	1.2	59.3	0.4	0.1	1.2	0.7

Figure 4.6. Impact of Traffic Control Functionality on the Frequency of Crashes

4.3.4. Road Data: Road Class (RD_CLASS)

Figure 4.7 shows the impact of the class of traffic way on the frequency of fatal and injury crashes in Illinois highways. The results indicate that urban—controlled access highways had the highest percentage of fatal and injury crashes, while rural—controlled access highways accounted for the second highest percentage of fatal crashes and urban—toll roads accounted for the second highest percentage of injury crashes.

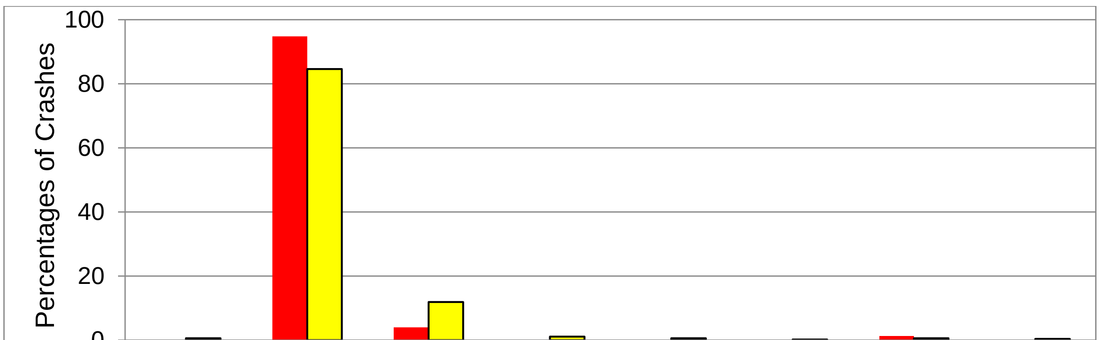


	Rural—unmarked state highway	Rural—controlled access highway	Rural—other marked state highway	Rural—county/local road	Rural—toll road	Urban—controlled access highway	Urban—other marked state highway	Urban—unmarked state highway	Urban—city street	Urban—toll road
Fatal%	0	35.53	0	0	5.26	50	1.32	0	0	7.89
Injury%	0.1	8.94	0.01	0.2	2.47	46.65	1.45	0.49	3.05	36.64

Figure 4.7. Impact of Traffic Way Class on the Frequency of Fatal and Injury Crashes

4.3.5. Road Data (Road Surface Condition)

Figure 4.8 shows the impact of the road surface condition on the frequency of fatal and injury crashes in Illinois. The results show that the majority of work zone crashes occur on dry roadway surfaces and only 3.9% and 11.9% of total fatal and injury crashes, respectively, occur on wet roadway surfaces. This indicates that the wet road surface condition is not one of the significant causes of work zone crashes on highways in Illinois.



	Not Stated (96-2003)	Dry	Wet	Snow/slush	ice	Sand/mud/dirt/etc.	Other	Unknown
Fatal%	0	94.74	3.95	0	0	0	1.32	0
Injury%	0.61	84.55	11.92	1.13	0.6	0.18	0.6	0.41

Figure 4.8. Impact of Road Surface Condition on the Frequency of Fatal and Injury Crashes

4.3.6. Time Data (Time of Accident)

Figure 4.9 shows the impact of the time of day on the frequency of fatal and injury crashes in Illinois. The results indicate that 29.2% and 43.4% of fatal crashes and injury crashes, respectively, occurred at nighttime hours (20:00 - 6:00). These findings suggest that nighttime work zones create safety risks for traffic and cause a significant number of fatal and injury crashes. The increasing nighttime risks must be carefully considered and the visibility of traffic control and lighting designs for nighttime work zones must be improved to increase alertness of nighttime drivers. The results also show that 32.1% and 33.9% of fatal and injury crashes, respectively, occur in daytime.

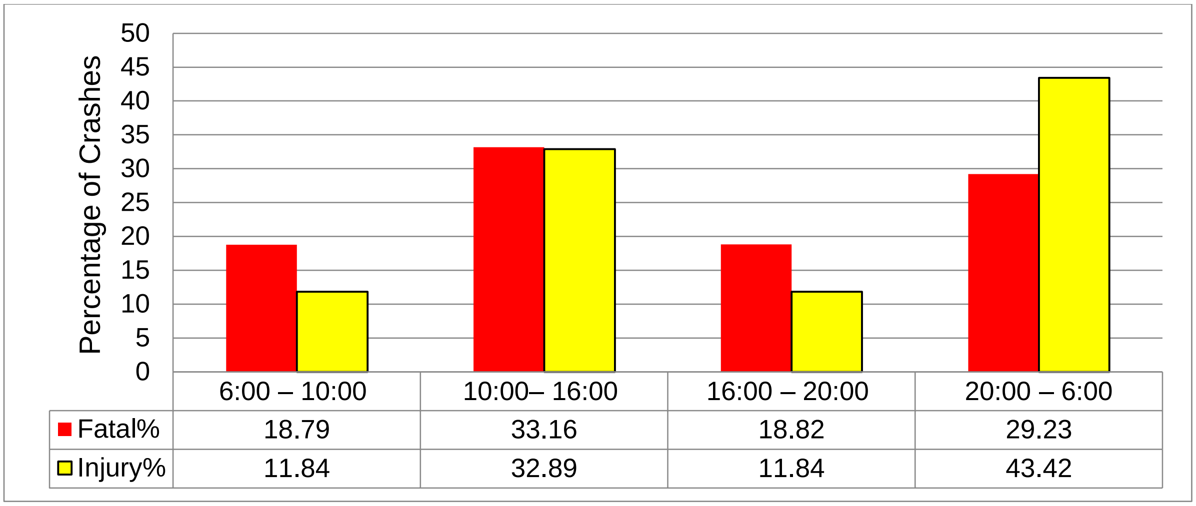
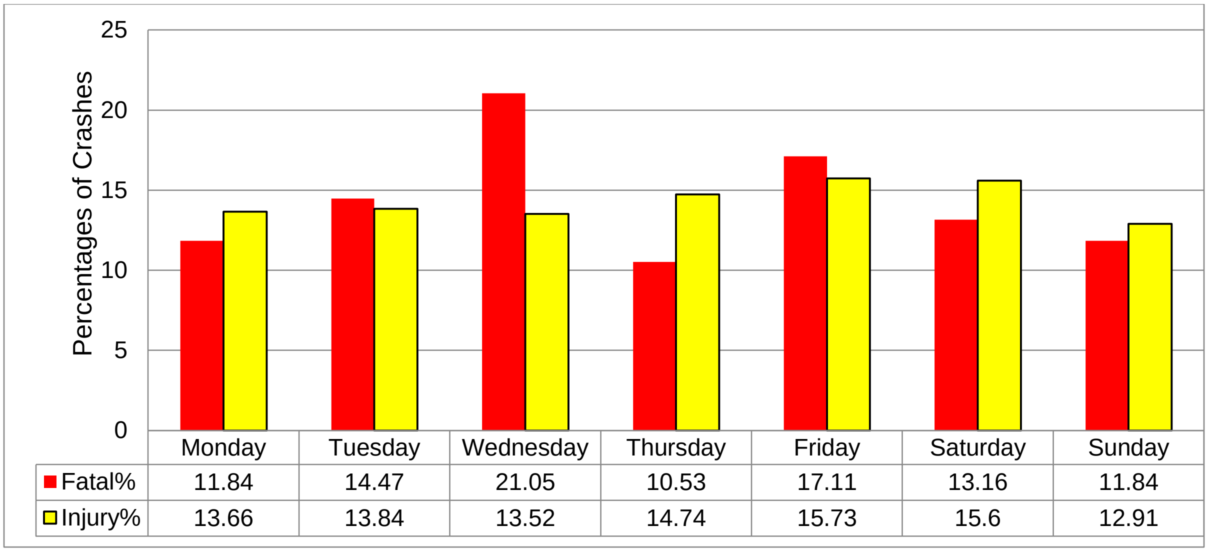


Figure 4.9. Impact of the Time of Day on the Frequency of Fatal and Injury Crashes

4.3.7. Time Data (Day of the Week)

Figure 4.10 shows the impact of the day of the week on the frequency of fatal and injury crashes. The results show that there is no significant difference between the types of work zone crashes and their distribution over the days of the week. For example, the largest difference in fatal work zone crashes was equivalent to 10.5%, which represented the difference between crashes occurring on Wednesday, 21.1%, and those occurring on Thursday, 10.5%, and Sunday, 11.8%. The results also show that the lowest percentage of fatal and injury work zone crashes occur on Sunday, which can be attributed to the reduced work zone operations on that day of the week.



	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Fatal%	11.84	14.47	21.05	10.53	17.11	13.16	11.84
Injury%	13.66	13.84	13.52	14.74	15.73	15.6	12.91

Figure 4.10. Impact of the Weekday on the Frequency of Fatal and Injury Crashes

4.3.8. Crash Data (Type of Collision)

This section analyzes the types of collisions caused by fatal and injury crashes as shown in Figure 4.11. The results of this analysis show that the most frequent type of collision was rear-end for both types of crashes, 38.2% fatal crashes and 54.6% injury crashes, followed by fixed- object collision crashes, 21%, fatal crashes and 15.2 injury crashes. The results indicate that rear-end and fixed-object are the leading types of collisions for fatal and injury work zone crashes in Illinois.

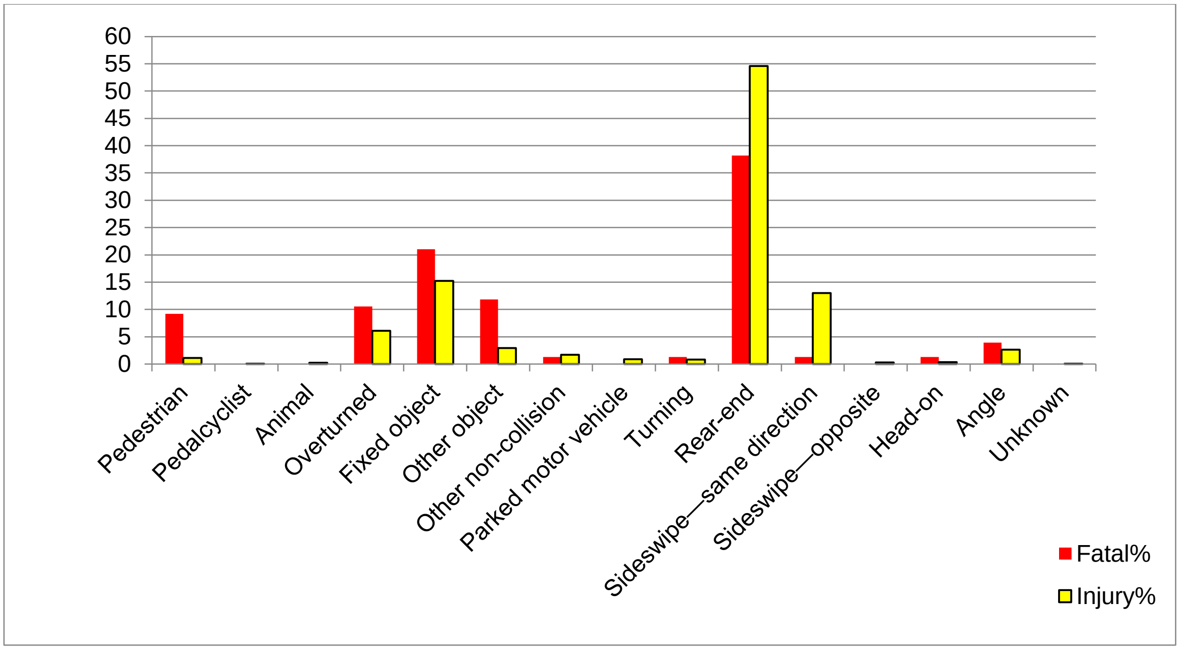
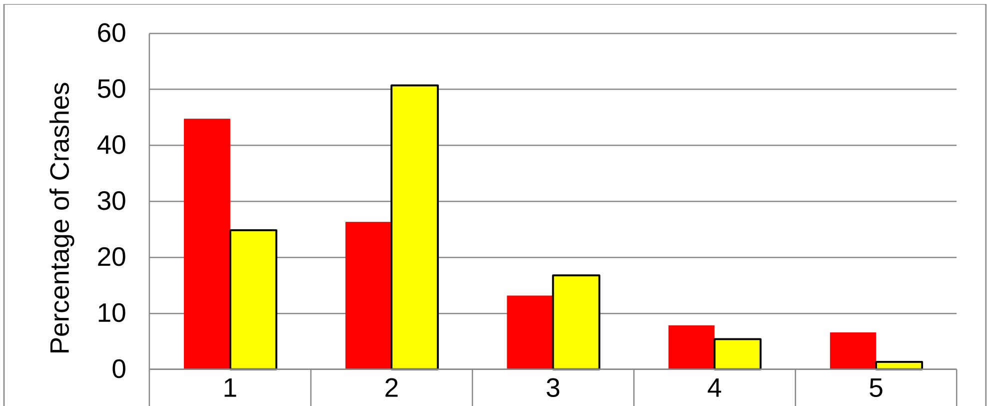


Figure 4.11. Type of Collision Caused by Fatal and Injury Crashes

4.3.9. Crash Data (Number of Vehicles Involved)

In this analysis, the severity of various types of crashes was analyzed using a second metric that represents the total number of vehicles involved in the crash. The results of this severity analysis are shown in Figure 4.12. The results show that almost half of fatal work zone crashes (44.7%) involved one vehicle only, while a small percentage (8%) of these crashes involved four or more vehicles. On the other hand, (24.9%) of injury work zone crashes involved one vehicle only, while 50.7% of this type of crashes was caused by two vehicles collision. This indicates that (a) fatal crashes are more likely to involve one vehicle compared with injury crashes, (b) a significant majority of all types of crashes involves one or two vehicles, and (c) injury crashes are more likely to involve two vehicles.

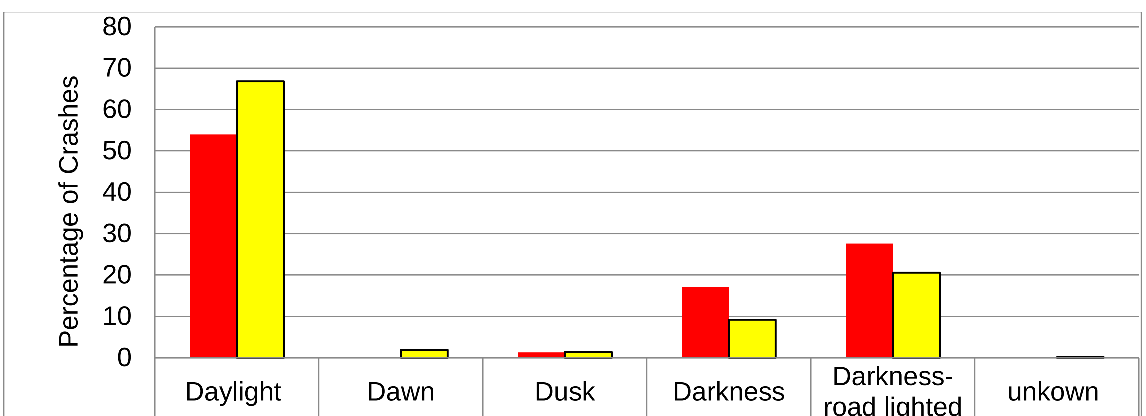


	1	2	3	4	5
Fatal	44.74	26.32	13.16	7.89	6.58
Injury	24.88	50.72	16.78	5.43	1.35

Figure 4.12. Total Number of Vehicles Involved in Fatal and Injury Crashes

4.3.10. Light and Weather Data (Light Conditions)

The impact of light conditions on the frequency of fatal and injury crashes in Illinois is shown in Figure 4.13 The results show that 54% of fatal crashes and 67% of injury crashes occurred in daylight, while the remaining crashes (34% fatal crashes and 29% injury crashes) occurred on dark roads or lighted roads in nighttime, as shown in Figure 4.13. The results also show that 17% of fatal crashes occurred at night on unlighted roads compared with 9% of total injury crashes that occurred in similar lighting conditions.



	Daylight	Dawn	Dusk	Darkness	Darkness-road lighted	unkown
Fatal	53.95	0	1.32	17.11	27.63	0
Injury	66.85	1.9	1.37	9.16	20.55	0.17

Figure 4.13. Impact of Light Conditions on the Frequency of Crashes

4.3.11. Weather Data (Weather)

The impact of weather conditions on the frequency of fatal and injury crashes in Illinois is shown in Figure 4.14. Results show that the majority of work zone crashes occurred during clear weather conditions. Only 2.6% of fatal crashes and 8.4% of injury crashes occurred in rainy conditions, which reflects that weather is not a major cause of work zone crashes on Illinois highways.

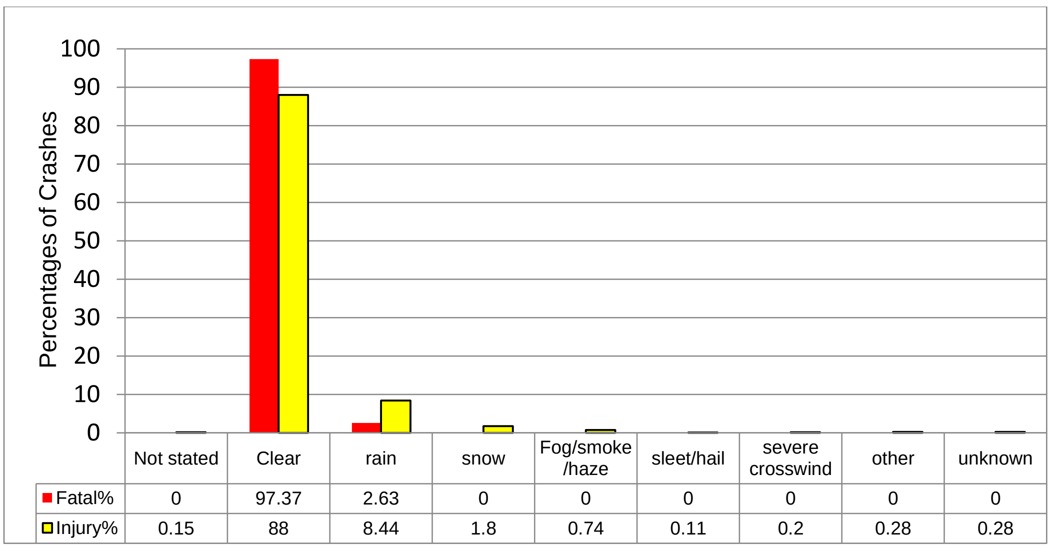
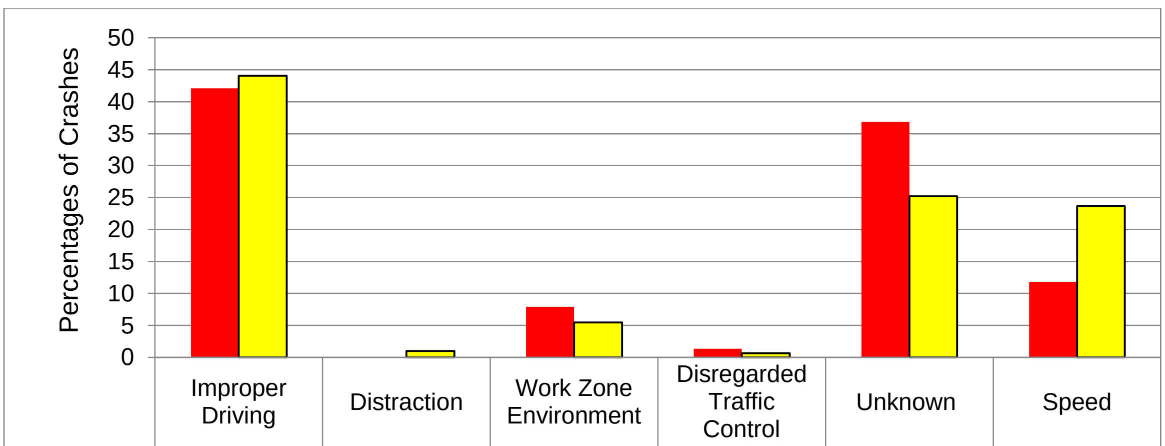


Figure 4.14. Impact of Weather Conditions on the Frequency of Crashes

4.3.12. Contributing Causes

The contributing cause variable represents various drivers' actions that contributed to crashes. In the National Highway Traffic Safety Administration (NHTSA) data files, this variable has 35 possible values representing potential contributing causes that are related to drivers' actions. In this analysis, the 35 possible values are regrouped and divided into six major contributing causes: (1) improper driving, (2) distraction, (3) work zone environment, (4) disregarding traffic control, (5) speed, and (6) an unknown cause. The impact of these contributing causes on the frequency of fatal and injury crashes in Illinois is shown in Figure 4.15. The results show that improper driving was the main contributing cause, accounting for 42% and 44% of fatal and injury work zone crashes, respectively, followed by speed and work zone environment causes. In addition, it is observed that improper driving covers a number of driver actions such as following too closely, wrong side/way, improper turn, and right turn on red, as shown in Appendix A. Speed also covers several speed-related actions, and the work zone environment covers a number of subcategories such as: road engineering, surface, markings, and defects, road construction, obscured vision, and improper lane usage. Therefore, it is important to attract the attention of drivers and increase awareness of work zones in order to minimize potential crash causes and, consequently, reduce the risks of fatal and injury crashes and improve traffic safety. Results also show that “Unknown” was the second highest category due to its selection in the crash report by police officers when they cannot identify the specific cause of crash.



	Improper Driving	Distraction	Work Zone Environment	Disregarded Traffic Control	Unknown	Speed
Fatal%	42.11	0	7.89	1.32	36.84	11.84
Injury%	44.06	0.99	5.46	0.63	25.2	23.66

Figure 4.15. Impact of Contributing Causes on the Frequency of Fatal and Injury Crashes

CHAPTER 5
IDOT AND NATIONAL SURVEYS

5.1. INTRODUCTION

Two identical online surveys were conducted to gather and analyze feedback from engineers and construction personnel in IDOT and other state DOTs on the effectiveness of TTC measures and safety devices such as flaggers and spotters in directing work zone traffic on freeways and expressways with a posted speed limit greater than 40 mph. The first survey was distributed to IDOT resident engineers, managers, supervisors, maintenance personnel, contractors, and consultants. Another version of the survey was distributed to other state DOTs. The survey was developed following the guidelines of the American Association for Public Opinion Research (AAPOR 2010). This chapter presents the results of analyzing and comparing the findings of the two surveys of IDOT and other state DOTs. Both surveys are identical and consist of three main sections, as shown in Appendix B. The first section asks respondents to identify the need, benefits, and risks of using flaggers in and around work zones. The second section requires respondents to evaluate spotter functions, benefits, and risks. The third section aims at collecting feedback from survey respondents on the effectiveness, need, and risks of using spotters instead of flaggers in work zones. The fourth section evaluated the effectiveness of using TTC devices and various safety measures in improving the safety of work zone access and egress points.

5.1.1. Analysis of Survey Respondents

Eighty complete responses were received from the survey that targeted IDOT engineers, personnel, and contractors. The respondents were classified based on their reported title, as shown in Figure 5.1. Twenty complete responses were received from 14 state DOTs in the national survey; three responses were received from Iowa and Alabama DOTs, two responses were received from Texas, Kansas, and Minnesota DOTs., and one response was received from Arizona, Florida, Connecticut, Michigan, Mississippi, Missouri, Montana, Virginia, and Washington DOTs. Table 5.1 summarizes the number of responses received from each participating state DOT.

Table 5.1. Number of Complete Responses Received from State DOTs

State	Number of Responses	Percent
Alabama	2	10%
Arizona	1	5%
Connecticut	1	5%
Florida	1	5%
Iowa	3	15%
Kansas	2	5%
Michigan	1	5%
Minnesota	2	10%
Mississippi	1	5%
Missouri	1	5%
Montana	1	5%
Texas	2	10%
Virginia	1	5%
Washington	1	5%

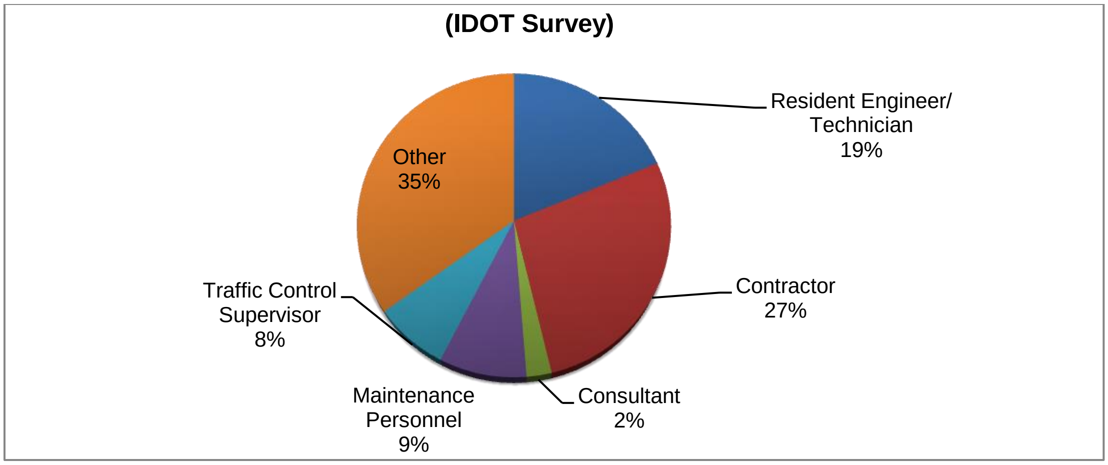


Figure 5.1. Distribution of IDOT survey respondents according to reported titles

5.2. BENEFITS AND RISKS OF USING FLAGGERS

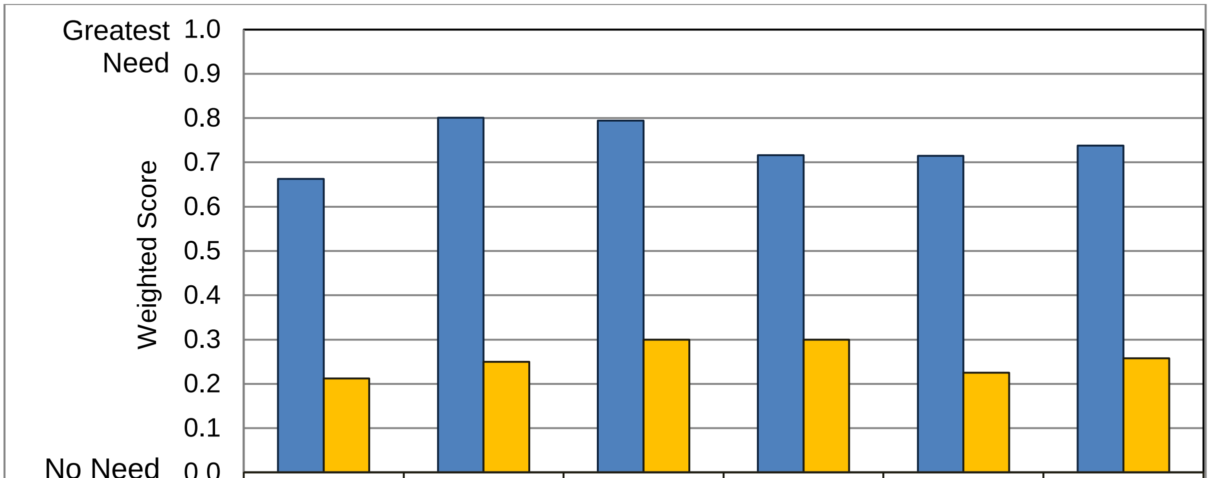
In DOT and national surveys, respondents were asked to assess the level of need, effectiveness, benefit, or risk of using flaggers on freeway/expressway work zones. Each respondent needs to select one category from five available alternatives that represent the level of need, effectiveness, benefit, or risk. For example, the level of need in the survey can be selected as “no need” that is represented numerically by “0.0”, “low need” represented by “0.25”, “moderate need” represented by “0.5”, “high need” represented by “0.75”, and “greatest need” represented by “1.0”. Similarly, a level of risk/hazard equivalent to “0.0” indicates “lowest risk” while “1.0” indicates “highest risk”. Weighted scores were calculated for each question in the survey to compare the average scores obtained from both surveys.

5.2.1. Need for Flagger Functions

Survey respondents were asked to identify the level of need for a flagger to perform a set of functions, including slowing down traffic, alerting road users approaching the work zone, warning workers of errant drivers, and directing traffic when construction trucks enter and exit the work zone. The results of the weighted scores for each function in

IDOT and national surveys are shown in Figure 5.2. In the IDOT survey, the two functions that received the highest weighted score were “slow the speed of oncoming traffic” and “warn workers of errant drivers and vehicle intrusion into work zone”, which received weighted scores of 0.801 and 0.794, respectively. In the national survey, the two functions that received the highest weighted score were “warn workers of errant drivers and vehicle intrusion into work zone” and “direct traffic when construction trucks enter the work zone”, which received a score of 0.30 each.

The average score for the need of flaggers to perform various safety and mobility functions on freeway and expressway work zones was 0.738 in the IDOT survey and 0.258 in the national survey, as shown in Figure 5.2. This indicates that other state DOTs considered that the level of need for flaggers in these types of work zones ranges from “no need” to “moderate need”, as shown in Figure 5.2. In addition, a number of state DOTs, including Florida, Minnesota, Michigan, and Virginia DOTs, stated that they no longer use flaggers in these types of work zones.



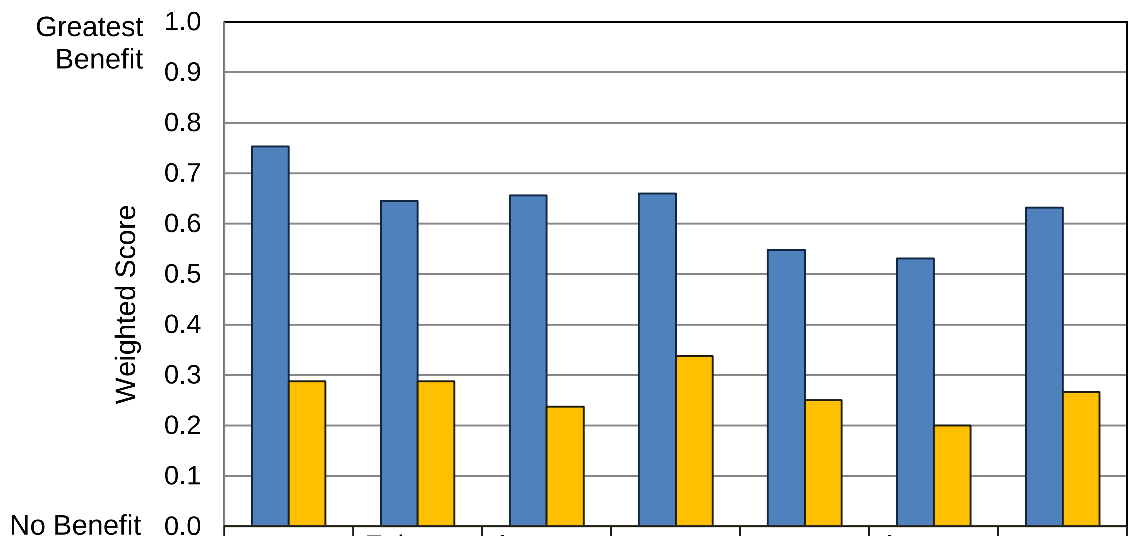
	Alert road users approaching the work zone	Slow the speed of oncoming traffic	Warn workers of errant drivers and vehicle intrusion into work zone	Direct traffic when construction trucks enter the work zone	Direct traffic when construction trucks exit the work zone	Average
IDOT Survey	0.663	0.801	0.794	0.716	0.715	0.738
National Survey	0.213	0.250	0.300	0.300	0.225	0.258

Figure 5.2. Weighted Scores for Need of Flagger Functions from IDOT and National Surveys

5.2.2. Benefit of Flagger Functions

In the national survey, the level of benefits that can be gained from using flaggers in freeway/expressway workzones received very low weighted scores ranging from 0.20 to 0.338, where a score of "0.0" represents "no benefit" and a score of "1.0" indicates "greatest benefit", as shown in Figure 5.3 IDOT survey respondents gave relatively higher weighted scores for flagger benefits, ranging from 0.531 to 0.753.The flagger benefit that received the highest weighted score in national and IDOT surveys was "enhance road users safety" and "improve workers safety", which scored 0.338 and 0.753, respectively. The flagger benefit with the lowest weighted score was "improve compliance with traffic speed limit", which scored 0.20 in the national survey and 0.531 in the IDOT survey. The average score for the benefits that can be gained from using flaggers on freeway and expressway work zones was 0.632 in the IDOT survey and

0.267 in the national survey, as shown in Figure 5.3. This indicates that other state DOTs considered that there was “no benefit” or only a “moderate benefit” gained from using flaggers in these types of work zones.



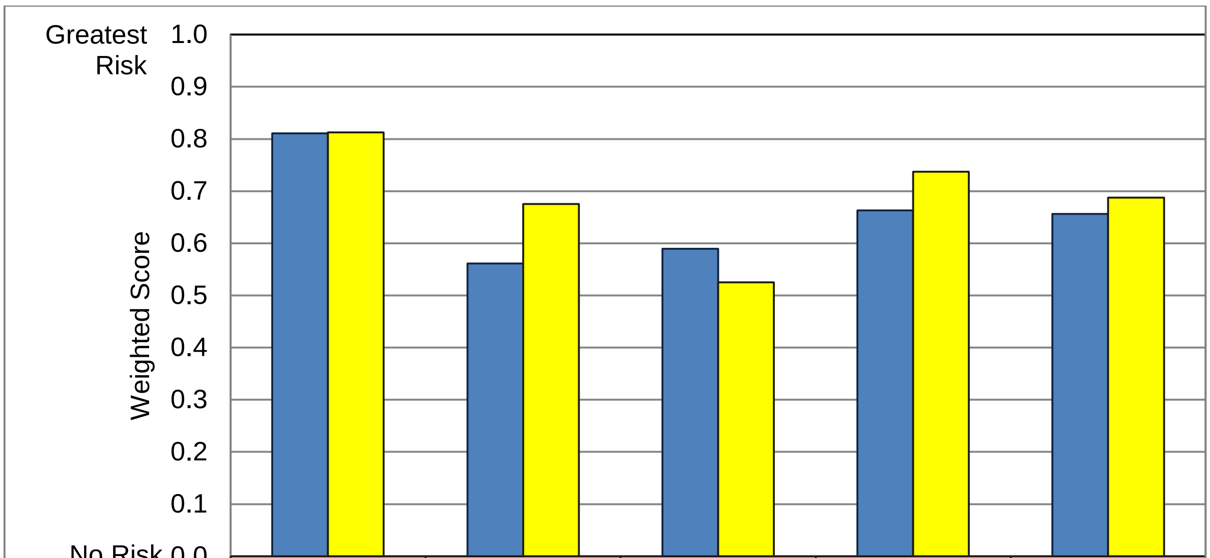
	Improve workers safety	Enhance safety of trucks entering work zone	Improve safety of trucks exiting work zone	Enhance road users safety	Improve traffic mobility	Improve complian ce with traffic speed limit	Average
IDOT Survey	0.753	0.645	0.656	0.660	0.548	0.531	0.632
National Survey	0.288	0.288	0.238	0.338	0.250	0.200	0.267

Figure 5.3. Weighted Scores for Level of Benefit of Flagger Functions from IDOT and National Surveys

5.2.3. Risk/Hazard Caused by Using Flaggers

In this question, survey respondents were asked to report the level of risks that might result from using flaggers in freeway/expressway work zones. The weighted scores for the listed risks were similar in IDOT and national surveys. Both scores were above 0.5, where a score of “0.0” represents “no risk” and a score of “1.0” indicates “greatest risk”, as shown in Figure 5.3. The risk that had the highest score was “exposure of flaggers to traffic hazards and injuries” with scores of 0.813 and 0.811 in IDOT and national surveys, respectively. This highlights the high level of exposure to hazards that flaggers experience in this type of work zone. The risk that had the second highest score was “flaggers encroaching into open traffic lanes” with a score of 0.738 in the national survey and 0.663 in the IDOT survey.

The average score for the risks and hazards that can be caused by using flaggers on freeway and expressway work zones was 0.656 in the IDOT survey and 0.688 in the national survey, as shown in Figure 5.4. This indicates that both IDOT respondents and other state DOTs respondents identified the level of risks caused by using flaggers in these types of work zones to be between “moderate risk” and “greatest risk”.

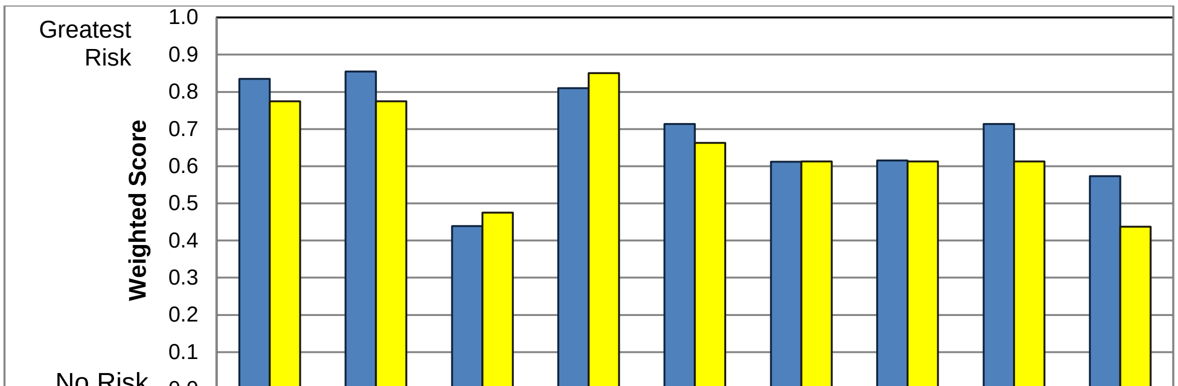


	Exposure of flagger to traffic hazards and injuries	Exposure of flagger to work zones hazards and injuries	Flagger causing excessive slow down of traffic & increasing traffic backups	Flaggers encroaching into open traffic lanes	Average
IDOT Survey	0.811	0.561	0.590	0.663	0.656
National Survey	0.813	0.675	0.525	0.738	0.688

Figure 5.4. Weighted Scores for Level of Risk/Hazard Caused by Using Flaggers from IDOT and National Surveys

5.2.4. Risk/Hazard to Flaggers in Different Work Zone Conditions

In this question, respondents were asked to identify the level of risk to flaggers in different work zone conditions. The weighted scores of the received responses in both surveys are shown in Figure 5.5. Results from both surveys were similar in most work zone conditions. Daytime work zones received the lowest weighted scores of 0.475 and 0.439 in the national and IDOT surveys, respectively. Work zones with nighttime activities, curves and hills received the highest weighted scores of 0.850/0.810, 0.775/0.835, and 0.775/0.855 in the national and IDOT surveys, respectively. This highlights the increased level of risk in these conditions and the need to find alternative and safer solutions to control and minimize risks/hazards to flaggers.



	Curves	Hills	Daytime work zones	Nighttime work zones	Glare from sun	Glare from vehicle headlights	Glare from nighttime work zone lighting	Adverse weather conditions	Lack of visibility due to constructi on-related dust or temporary structures
IDOT Survey	0.835	0.855	0.439	0.810	0.714	0.612	0.615	0.714	0.573
National Survey	0.775	0.775	0.475	0.850	0.663	0.613	0.613	0.613	0.438

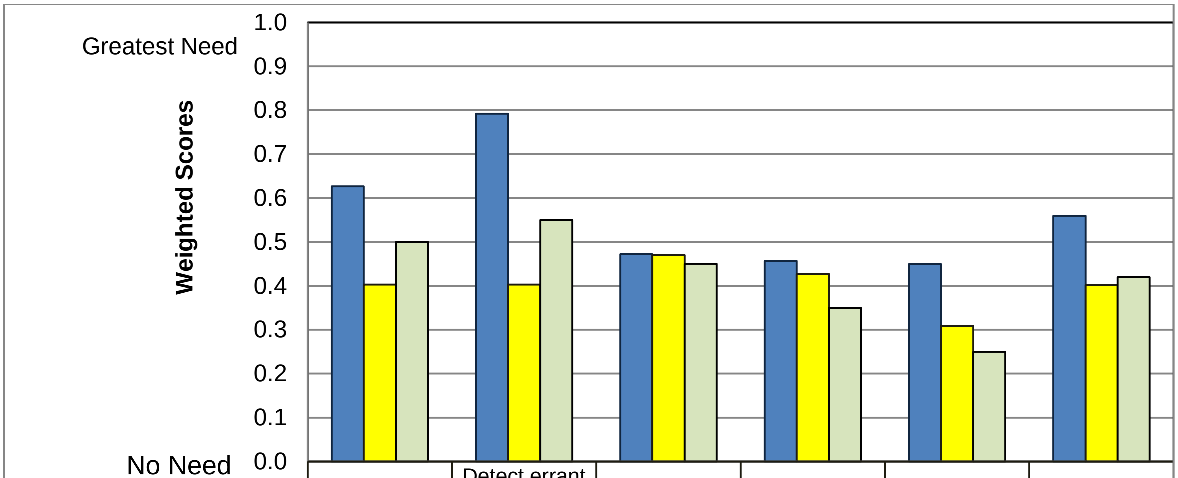
Figure 5.5. Weighted Scores for the Level of Risk/Hazard to Flaggers in Work Zone Conditions from National and IDOT Surveys

5.3. BENEFITS AND RISKS OF USING SPOTTERS

The second section in both surveys was designed to evaluate the benefits and risks of using spotters in freeway/expressway work zones to warn workers of errant drivers. A spotter was defined as a trained person whose sole duty is to monitor traffic and warn workers of errant drivers or other hazards using an effective warning device, such as a whistle or an air horn. National survey respondents were asked if their organizations allow or recommend the use of spotters to warn workers of errant drivers in freeway and expressway work zones with speed limits greater than 40 mph; five respondents answered “yes” while ten respondents answered “no”. The following section compares the average scores provided by IDOT responses, state DOT responses, and the state DOT responses that reported prior use of spotters in the national survey.

5.3.1. Need for Potential Spotter Functions

In this question, respondents were asked to evaluate the level of need for various potential spotter functions such as “Warn workers of oncoming traffic”. Figure 5.6 shows the calculated weighted scores for each potential spotter function for the IDOT and national surveys. In the IDOT survey, the two spotter functions that received the highest weighted scores were “Detect errant drivers and warn workers using effective warning devices”, and “ Warn workers of oncoming traffic,” which received scores of 0.792 and 0.627, respectively, while other functions received scores ranging from 0.449 to 0.471. The average score for the need of spotters to perform various safety and mobility functions on freeway and expressway work zones was 0.559, 0.402, and 0.420 from IDOT respondents, state DOTs participating in the national survey, and state DOTs with prior experience in using spotters, respectively, as shown in Figure 5.6. This indicates that IDOT and other state DOTs considered the level of need for spotters in these types of work zones as “moderate need”.

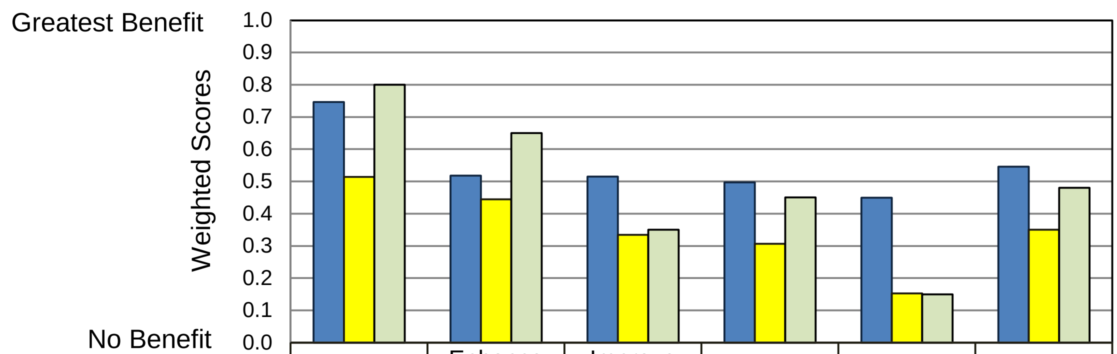


	Warn workers of oncoming traffic	Detect errant drivers and warn workers using effective warning devices	Warn workers of construction equipment hazards in the work zone	Guide trucks/equipment entering the work zone	Guide trucks/equipment exiting the work zone	Average
IDOT Survey	0.627	0.792	0.472	0.457	0.450	0.559
All Participating DOTs	0.403	0.403	0.470	0.427	0.309	0.402
DOTs Deploying Spotters	0.5	0.55	0.45	0.35	0.25	0.42

Figure 5.6. Weighted Scores for the Level of Need for Potential Spotter Functions

5.3.2. Benefits of Potential Spotter Functions

In this question, survey respondents were asked to evaluate the level of potential benefits that can be gained by deploying spotters in freeway/expressway work zones. Weighted scores were calculated from survey responses for each spotter function. Figure 5.7 shows the weighted scores received from the IDOT survey and national survey. The greatest benefit of using spotters was “Improve workers safety” which received 0.747, 0.514, and 0.80 from IDOT respondents, all state DOTs, and state DOTs with prior experience in using spotters, respectively, as shown in Figure 5.7. The function “Enhance trucks entering the work zone” received a weighted score of 0.650 from state DOTs with prior experience in using spotters.



	Improve workers safety	Enhance safety of trucks entering work zone	Improve safety of trucks exiting work zone	Enhance road users safety	Improve traffic mobility	Average
IDOT Survey	0.747	0.519	0.516	0.497	0.450	0.546
All Participating DOTs	0.514	0.445	0.334	0.306	0.153	0.350
DOTs Deploying Spotters	0.800	0.650	0.350	0.450	0.150	0.480

Figure 5.7. Weighted Scores for the Level of Benefits for Potential Spotter Functions

5.3.3. Potential Risks Caused by Using Spotters

In this question, survey respondents were asked to identify the level of risk of two potential hazards that can be caused by using spotters in freeway/expressway work zones. Figure 5.8 shows the weighted scores for both hazards in the national and IDOT surveys. The hazard of “exposure of spotter to traffic hazards and injuries” received the highest weighted score of 0.544, 0.720, and 0.70 from IDOT respondents, all state DOTs, and state DOTs with prior experience in using spotters, respectively.

Figure 5.8. Weighted Scores for the Level of Risk that can be caused by Spotters on Freeway/Expressway Work Zones

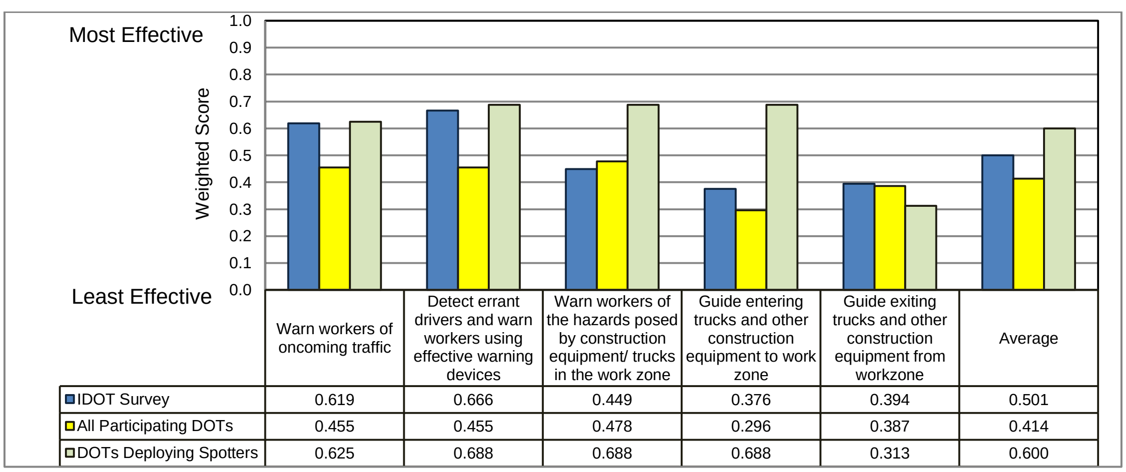
5.4. USING SPOTTERS INSTEAD OF FLAGGERS

This section of the survey gathered respondents' feedback on the effectiveness of using spotters instead of flaggers in freeway and expressway work zones with speed limits greater than 40 mph.

In this section, respondents were asked to identify: (1) the level of effectiveness if spotters are used instead of flaggers to perform a set of functions; (2) the level of effectiveness achieved by replacing flaggers with spotters to accomplish various safety and mobility goals, (3) the potential impact of using spotters instead of flaggers in different work zone layouts, (4) the level of effectiveness of various measures that can be used to maximize work zone safety and mobility, (5) the level of effectiveness of various measures that can be used to improve the safety of access and egress points in freeway and expressway work zones, and (6) the effectiveness of various temporary traffic control (TTC) devices.

5.4.1. Effectiveness of Spotters in Performing Flagger Functions

In this question, survey respondents were asked to identify the level of effectiveness that might be achieved by replacing flaggers with spotters in performing flagger functions using a five-point scale that ranges from least effective “0.0” to most effective “1.0”. The main evaluated functions include (1) warn workers of oncoming traffic, (2) detect errant drivers and warn workers, (3) warn workers of the hazards, (4) guide entering trucks and other construction equipment to work zone, and (5) guide exiting trucks and other construction equipment from work zone. A weighted score was calculated for all functions in both surveys as shown in Figure 5.9. In the IDOT survey, the top two functions that received the greatest weighted scores were “warn workers of oncoming traffic” and “detect errant drivers and warn workers using effective warning devices” which received a score of 0.619 and 0.666, respectively. In the national survey, the top three functions that received the greatest weighted scores from state DOTs with prior experience in using spotters were “detect errant drivers and warn workers”, “guide entering equipment/trucks to work zone” and “warn workers of the hazards posed by construction equipment in the work zone”, which received a score of 0.688 each.

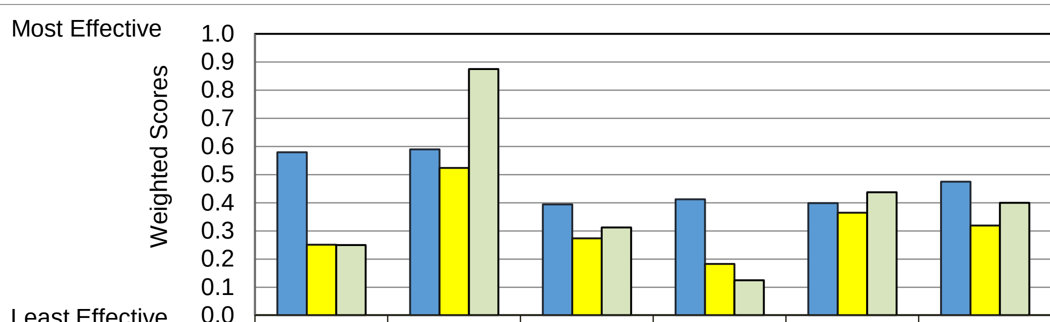


	Warn workers of oncoming traffic	Detect errant drivers and warn workers using effective warning devices	Warn workers of the hazards posed by construction equipment/ trucks in the work zone	Guide entering trucks and other construction equipment to work zone	Guide exiting trucks and other construction equipment from workzone	Average
IDOT Survey	0.619	0.666	0.449	0.376	0.394	0.501
All Participating DOTs	0.455	0.455	0.478	0.296	0.387	0.414
DOTs Deploying Spotters	0.625	0.688	0.688	0.688	0.313	0.600

Figure 5.9. Weighted Scores for Effectiveness of Using Spotters Instead of Flaggers to Perform Flagger Functions

5.4.2. Impact of Using Spotter on Safety and Mobility Goals

In this question, survey respondents were asked to identify the level of effectiveness achieved by using spotters instead of flaggers to accomplish a set of safety and mobility goals using a five-point scale that ranges from least effective "0.0" to most effective "1.0". The goal "enhance workers safety" received the greatest weighted score of 0.590, 0.523, and 0.875 from IDOT respondents, all state DOTs, and state DOTs with prior experience in using spotters, respectively, as shown in Figure 5.10. This highlights that state DOTs with prior experience in using spotters instead of flaggers reported a high level of effectiveness for this practice.

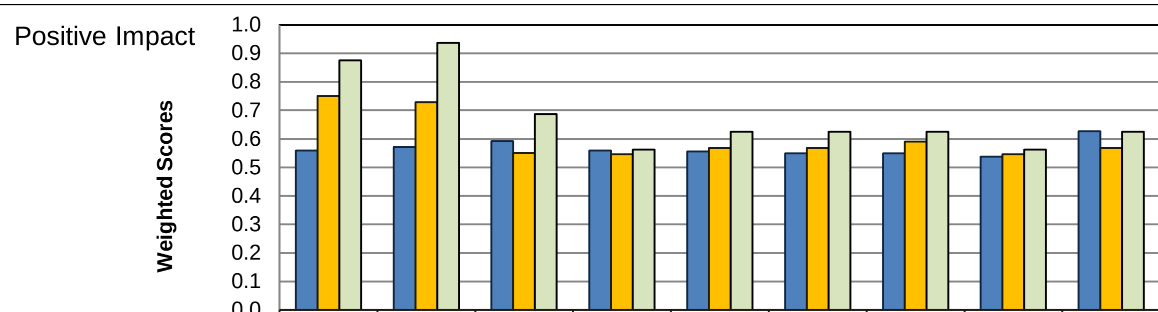


	Improve flagger and/or spotter safety	Enhance workers safety	Improve road users safety	Enhance traffic mobility	Enhance work zone access and egress	Average
IDOT Survey	0.580	0.590	0.394	0.412	0.399	0.475
All Participating DOTs	0.250	0.523	0.273	0.182	0.364	0.319
DOTs Deploying Spotters	0.250	0.875	0.313	0.125	0.438	0.400

Figure 5.10. Weighted Scores for Level of Effectiveness of Using Spotters Instead of Flaggers to Accomplish Safety and Mobility Goals

5.4.3. Impact of Using Spotters in Different Work Zone Layouts

In this question, survey respondents were asked to identify the level of impact of using spotters instead of flaggers in various work zone layouts based on a five-point scale that ranges from negative impact "0.0" to positive impact "1.0". In the IDOT survey, work zones that have "lane closure on freeways with high AADT" scored the highest weighted score of 0.62, where “0.5” indicates no impact and “1.0” indicates positive impact. The weighted scores for all other work zone types ranged from 0.538 to 0.592, as shown in Figure 5.11. The top three work zone layouts that received the greatest weighted scores were “short-duration work zone”, “very short-duration work zone”, and “long duration work zone” that received a score ranging from 0.550 to 0.938 from IDOT respondents, all state DOTs, and state DOTs with prior experience in using spotters, as shown in Figure 5.11.

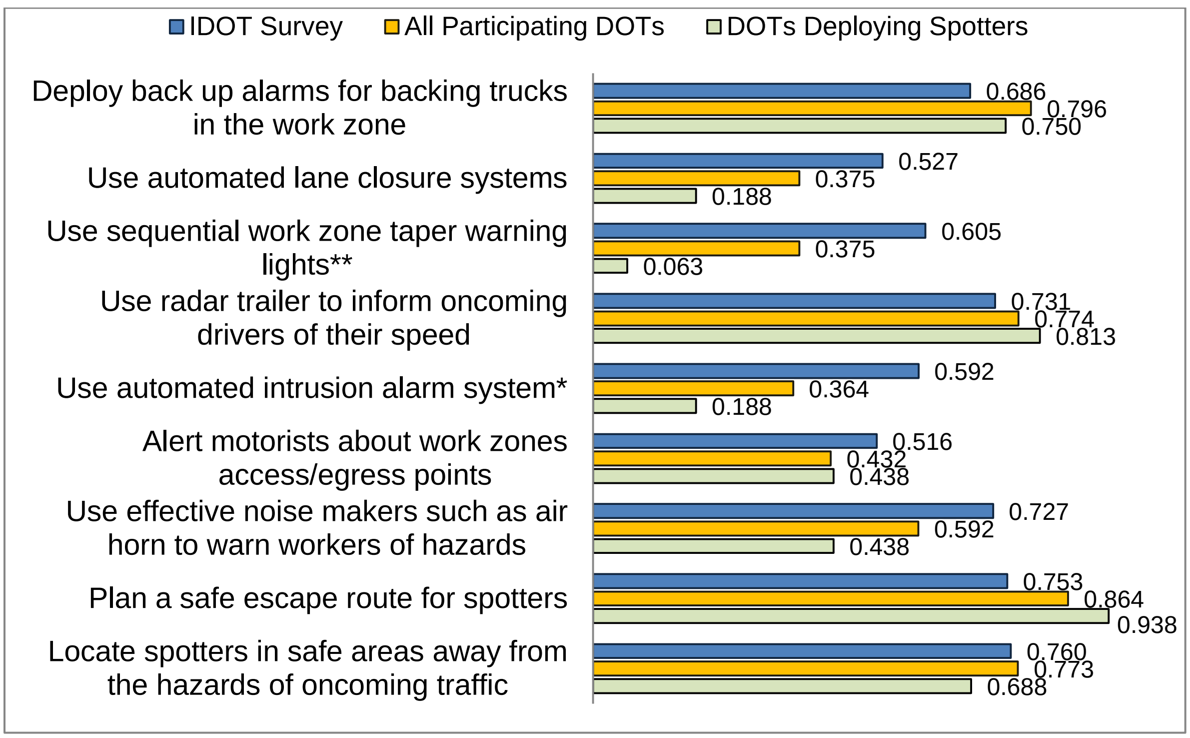


	Very short duration work zone < 15min	Short duration work zones	Long duration work zones	Lane closure at enter/exit ramp	One lane closure on highway	Two lane closure on highway	Lane closure with Truck Mounted Attenuator (TMA)	Lane closure on freeways with low Average Annual Daily Traffic (AADT)	Lane closure on freeways with high Average Annual Daily Traffic (AADT)
IDOT Survey	0.559	0.572	0.592	0.560	0.556	0.550	0.549	0.538	0.626
All Participating DOTs	0.751	0.728	0.550	0.546	0.568	0.568	0.591	0.546	0.568
DOTs Deploying Spotters	0.875	0.938	0.688	0.563	0.625	0.625	0.625	0.563	0.625

Figure 5.11. Weighted Scores for Impact of Using Spotters Instead of Flaggers in Different Work Zone Layouts

5.4.4. Measures to Maximize Work Zone Safety and Mobility

In this question, survey respondents were asked to identify the level of effectiveness of a set of measures used to maximize work zone safety and mobility if flaggers are replaced with spotters based on a five-point scale that ranges from least effective “0.0“ to most effective “1.0”. In the national survey, the top four measures that were reported to have the greatest effectiveness were “plan a safe escape route for spotters,” “deploy backup alarms for backing trucks in the work zone," "use radar trailer to inform oncoming drivers of their speed," and "locate spotter in safe areas away from hazards of oncoming traffic," which scored 0.864, 0.796, 0.773, and 0.773, respectively, as shown in Figure 5.12. In the IDOT survey, the measures that received the highest weighted score were "plan a safe escape route for spotters," and "locate spotter in safe areas away from hazards," which scored 0.753 and 0.760, respectively. State DOTs with prior experience in using spotters gave the highest weighted score of 0.938 to the measure "plan an escape route for spotters," which was very close to the level of greatest effectiveness.



* Automated intrusion alarm system: An automated system that detects the intrusion of errant vehicles into the work space and produces an audible, visual, and/or tactile alarm to notify downstream workers of the intrusion.

** Sequential work zone taper warning lights: A series of sequential flashing warning lights that can be placed on channelizing devices that form a merging taper in order to increase driver detection and recognition of the merging taper.

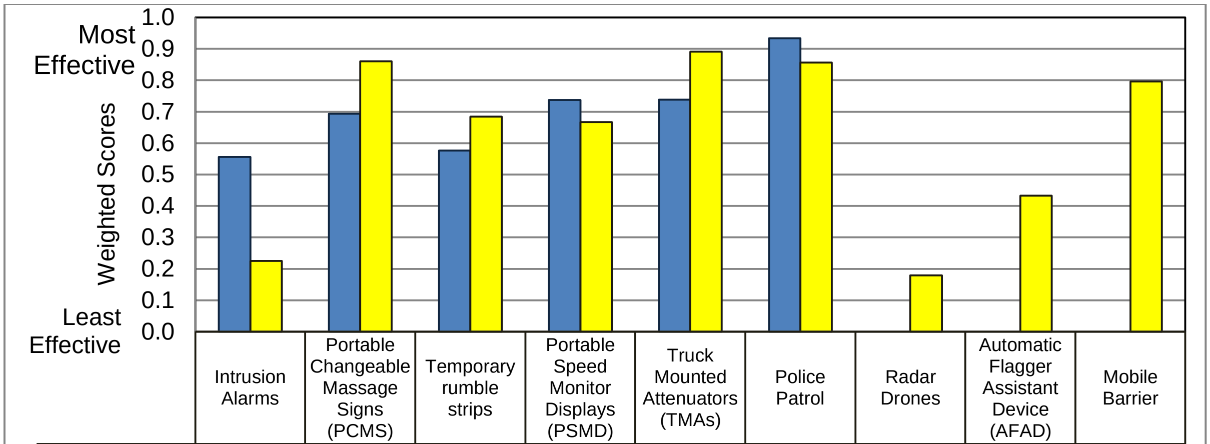
Figure 5.12. Level of Effectiveness of Safety Measures to Maximize Work Zone Safety and Mobility when Replacing Flaggers with Spotters

5.5. SAFETY MEASURES TO MAXIMIZE WORK ZONE SAFETY

In this section of IDOT and national surveys, respondents were asked to evaluate the effectiveness of new and existing temporary traffic control devices and various measures to improve the safety of access and egress points.

5.5.1. Effectiveness of Temporary Traffic Control (TTC) Devices

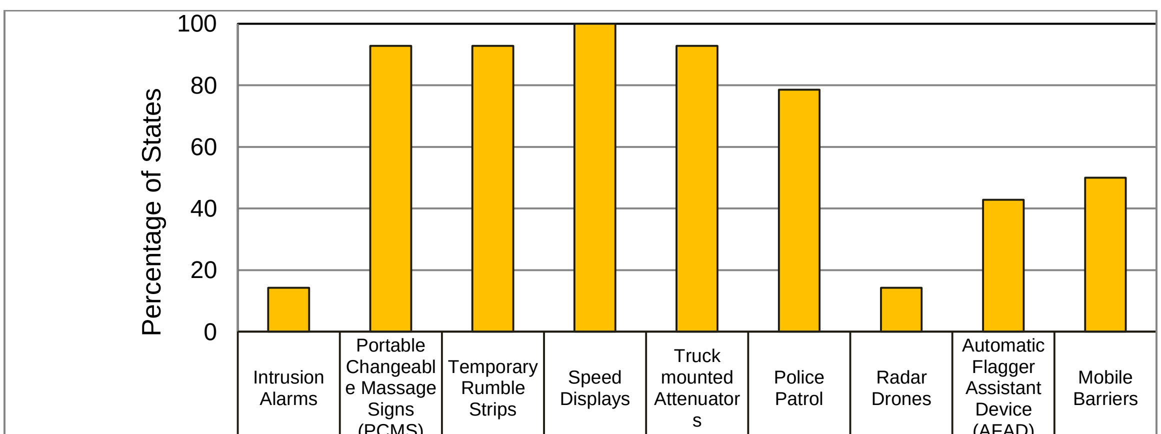
In this question, respondents of both surveys were asked to identify the level of effectiveness of various temporary traffic control (TTC) devices such as intrusion alarms, portable changeable message signs (PCMS), temporary rumble strips, speed displays, truck-mounted attenuators (TMAs), and police patrol. In addition, respondents in the national survey were asked to identify the level of effectiveness of radar drones, automated flagger assistance devices (AFAD), and mobile barriers, as shown in Figure 5.13. In the IDOT survey, the top four effective measures were police patrol, portable speed monitor displays, TMAs, and PCMS, which received a weighted score ranging between 0.693 and 0.934, as shown in Figure 5.13. In the national survey, the top four effective measures were TMAs, PCMS, police patrol, and mobile barrier, which received a weighted score ranging between 0.891 and 0.796, respectively, as shown in Figure 5.13.



	Intrusion Alarms	Portable Changeable Massage Signs (PCMS)	Temporary rumble strips	Portable Speed Monitor Displays (PSMD)	Truck Mounted Attenuators (TMAs)	Police Patrol	Radar Drones	Automatic Flagger Assistant Device (AFAD)	Mobile Barrier
IDOT Survey	0.556	0.693	0.577	0.737	0.738	0.934			
National Survey	0.225	0.860	0.684	0.667	0.891	0.857	0.179	0.432	0.796

Figure 5.13. Effectiveness of TTC Devices

National survey respondents were also asked to report if their state DOT recommended the deployment of the listed TTC devices. The percentages of states that recommended or deployed TTC devices are listed in Figure 5.14. All responding states reported that they recommended the deployment of speed monitor displays. The results also show that 92.9% of the responding states recommended the use of PCMS, TMAs, and temporary rumble strips, while 78.6% of the respondents recommended the use of police patrols, as shown in Figure 5.14.



	Intrusion Alarms	Portable Changeable Massage Signs (PCMS)	Temporary Rumble Strips	Speed Displays	Truck mounted Attenuators	Police Patrol	Radar Drones	Automatic Flagger Assistant Device (AFAD)	Mobile Barriers
Percentage of States	14.3	92.9	92.9	100.0	92.9	78.6	14.3	42.9	50.0

Figure 5.14. Percentage of Responding States that Recommend or use TTC Devices

5.5.2. Improving Safety of Access and Egress Points

In this question, the respondents were asked to identify the level of effectiveness of various measures to improve the safety of access and egress points in freeway and expressway work zones based on a five-point scale that ranges from 0.0 to 1.0. In the national survey, the top four effective measures were “incorporate access/egress into internal traffic control plan”, “build temporary ramp to provide median access from street overpass”, “improve lighting and visibility of access/egress points during nighttime work zone” and “use ITS technology to improve access/egress safety”, which received weighted score of 0.841, 0.80, 0.729 and 0.667, respectively. In the IDOT survey, the top five measures were: “improve lighting and visibility of access and egress points during nighttime work zone”, “incorporate access/egress into internal traffic control plans”, “equip the rear of construction vehicles entering the work zone with a warning sign”, and “deploy flagger to assist vehicles in entering and exiting work zone”, which received weighted scores of 0.793, 0.685, 0.637, 0.615, and 0.616, respectively, as shown in Figure 5.15. State DOTs that reported previous experience in using spotters in the national survey gave the measure “deploy spotter to assist vehicles entering and exiting work zone” a score of 0.750.

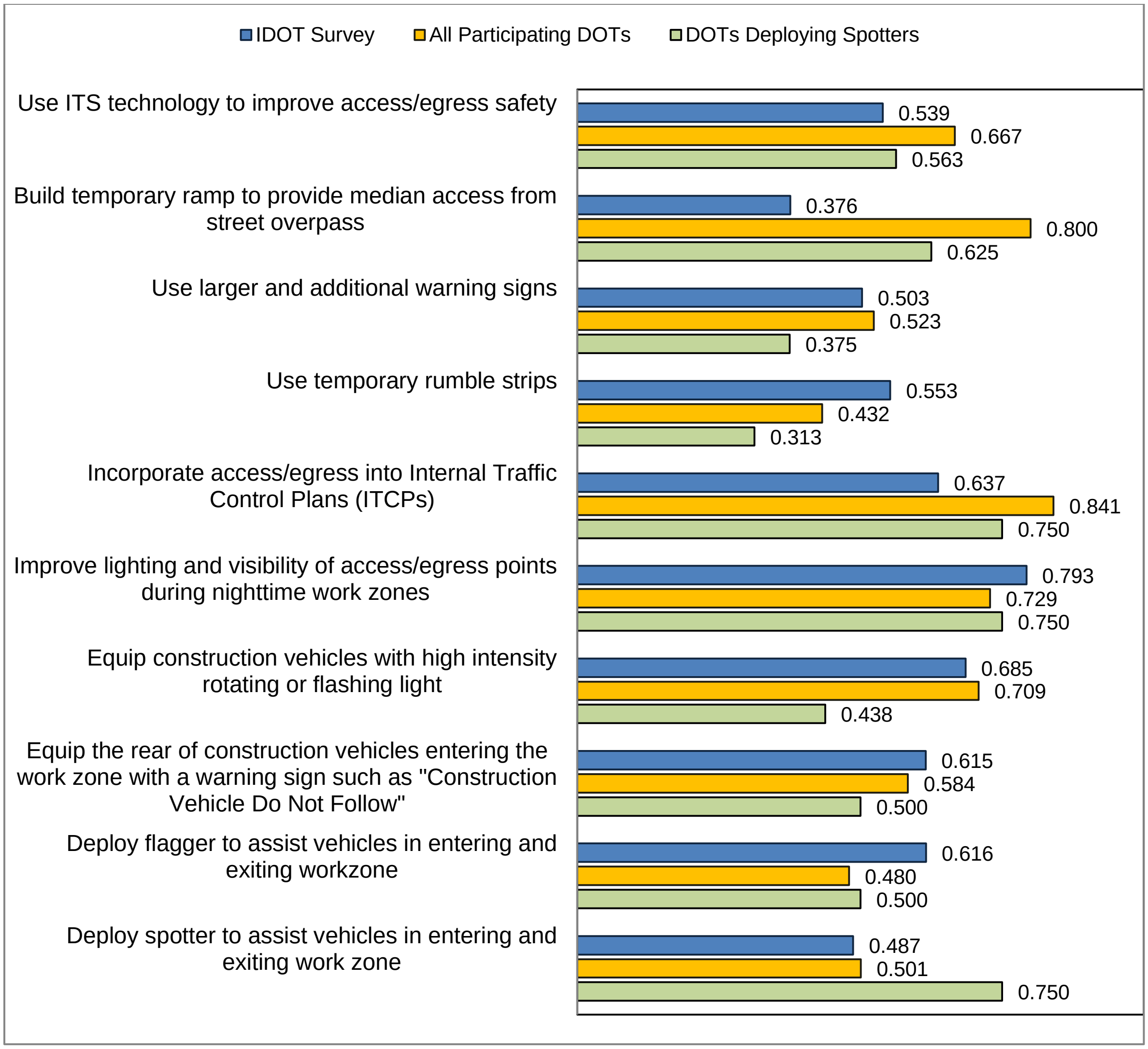


Figure 5.15. Weighted Scores for Level of Effectiveness of Measures to Improve Safety of Access and Egress Points

CHAPTER 6
OPTIMIZING TRADE-OFFS BETWEEN CONSTRUCTION COST AND TRAFFIC DELAY

6.1. INTRODUCTION

This chapter presents the development of a novel multi-objective optimization model to identify optimal tradeoffs between minimizing traffic delays and construction cost. The model is designed to optimize work zone layout parameters including: work zone segment length, starting time, lateral clearance, shoulder use, and work zone access. The model is developed in three main phases: (1) model formulation phase that identifies relevant decision variables, objective functions, and constraints of the model; (2) implementation phase that performs the optimization computations using multi-objective genetic algorithms and specifies the model input and output; and (3) performance evaluation phase that analyzes the performance of the developed model, as shown in Figure 6.1.

6.2. MODEL FORMULATION

This stage of the model focuses on formulating a novel model that is capable of optimizing all relevant work zone decision variables in order to identify and generate optimal tradeoffs between minimizing the delay of traffic and minimizing the construction cost of highways work zones. The formulation stage is accomplished in three steps: (1) identifying all relevant work zone decision variables that affect mobility and cost, (2) modeling the objective functions, and (3) representing all practical constraints.

6.2.1. Decision Variables

The purpose of this step is to identify all relevant work zone decision variables that affect mobility and cost based on the findings of a comprehensive literature review, a national survey, and field studies. First, the findings of a comprehensive literature review revealed that the work zone layout parameters that have an impact on mobility and cost include work zone length, construction start time, lateral clearance, and shoulder use (Benekohal 2010, Du and Chien 2014, Jiang and Adeli 2003, McCoy 1998, Meng and Weng 2013b). Accordingly, these four work zone parameters were integrated in the present model as decision variables, as shown in Figure 6.5.

Second, a national survey was conducted to gather feedback from DOT resident engineers and highway contractors from all states. In this survey, respondents were asked to identify the level of effectiveness of various measures that were recommended by the Federal Highway Administration to improve the mobility and safety of access and egress points in highway work zones (FHWA 2012). The top two measures that received the highest effectiveness scores in this national survey were “incorporate access/egress into internal traffic control plan”, and “build temporary ramp to provide median access from street overpass”, as shown in Figure 6.2 and

Figure 6.3. These two measures received the highest weighted scores of 0.841 and 0.80, respectively based on a five-point scale that ranges from 0.0 to 1.0. Accordingly, the aforementioned list of decision variables that were identified based on the literature review was expanded to include a fifth decision variable named “access and egress method”, as shown in Figure 6.1.

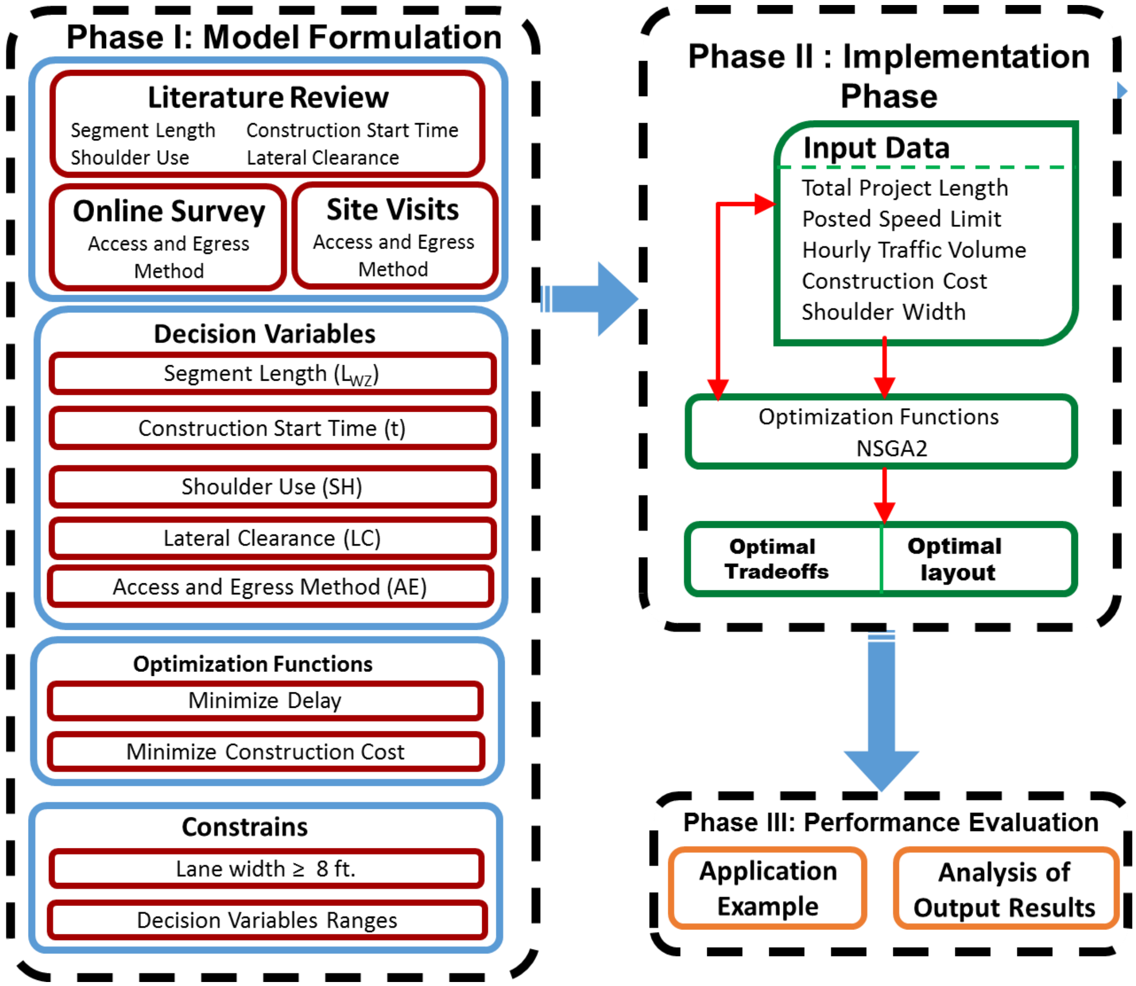


Figure 6.1. Model Formulation Phases

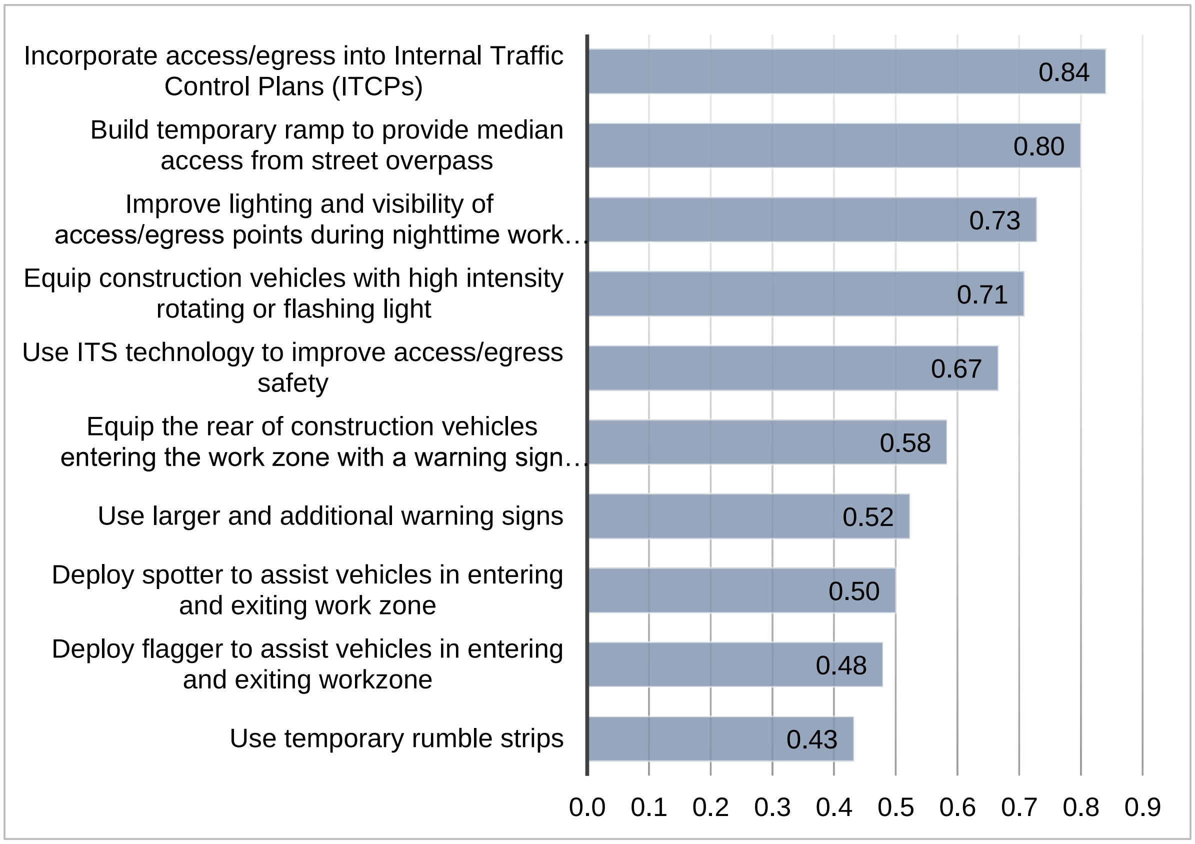


Figure 6.2. Effectiveness of Work Zone Access and Egress Measures

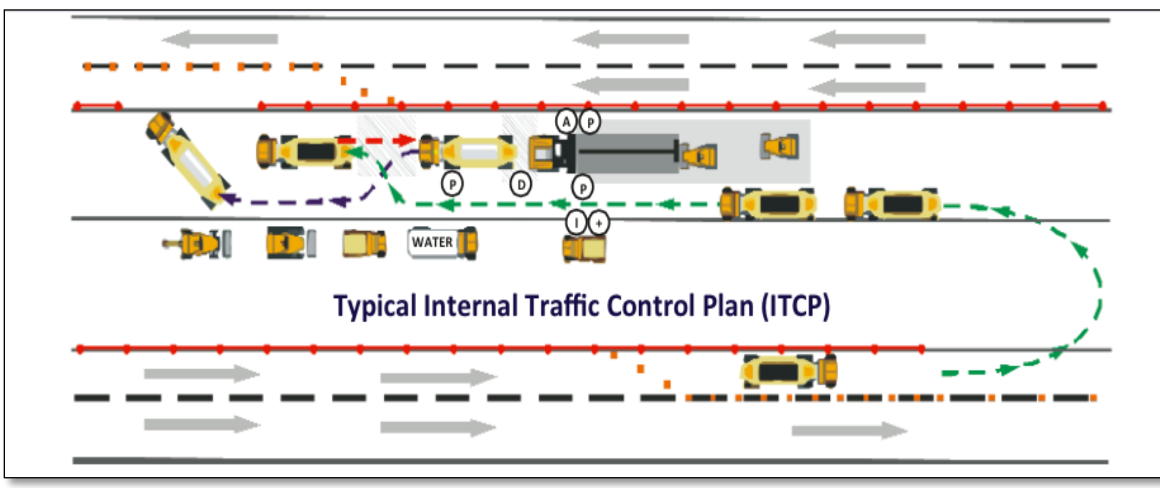


Figure 6.3. Example of incorporating access and egress in ITCP (FHWA 2012)

Third, field studies were conducted to investigate and identify measures to improve work zone mobility and safety. These field studies focused on (a) observing and studying various work zone layout measures and procedures for controlling work zone access and egress points such as using flaggers and/or spotters to manage and control the entry and exit of construction vehicles to and from the work zone; and (b) measuring and collecting field data on the impact of various access and egress methods on work zone traffic speed, queue length, and delay/stopping times as shown in Figure 6.4. The findings of these field studies confirmed that the access and egress method is an important decision variable that affects work zone mobility and safety. Accordingly, the identified decision variables in this model are (1) work zone segment length; (2) construction starting time; (3) lateral clearance; (4) shoulder use width; and (5) access and aggress method, as shown in Figure 6.5. The following sections provide a concise description of each of these variables and their impact on work zone mobility and cost.

Figure 6.4. Flagger Slows Down Traffic and Guides Trucks to Enter Work Zone

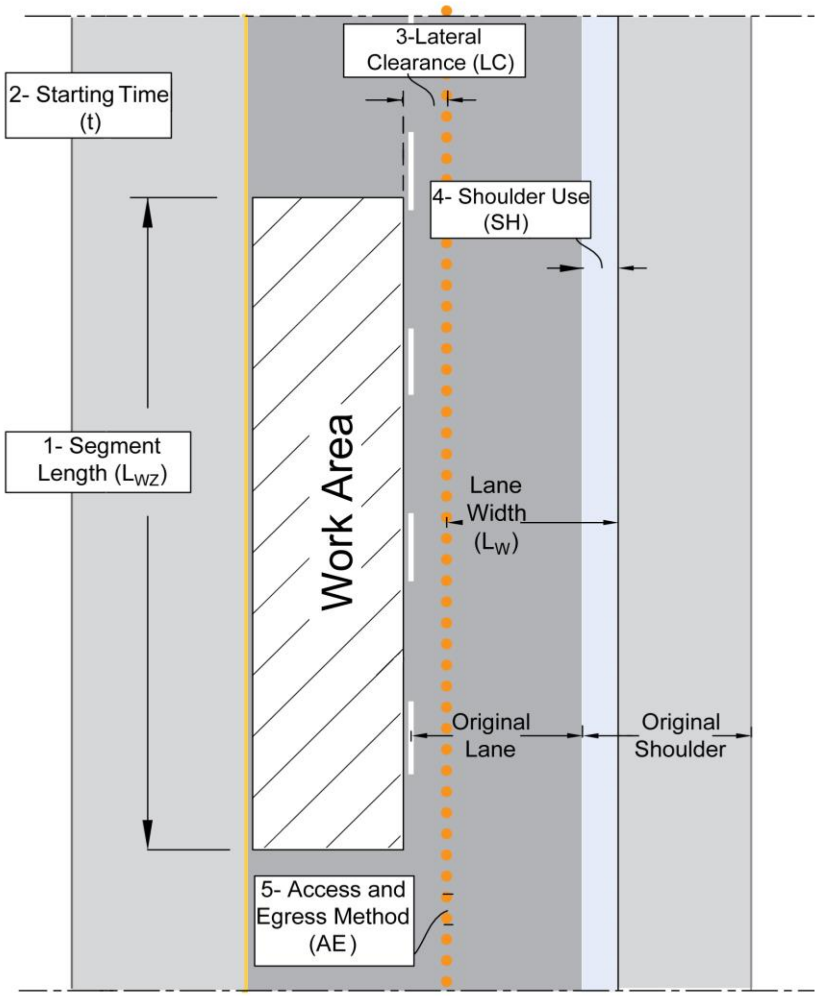


Figure 6.5. Work Zone Optimization Model Decision Variables

6.2.1.1. Work Zone Segment Length (L_{WZ})

The first decision variable in this model is the length of typical segment of work zone in miles L_{WZ}. The use of longer work zone segment lengths can reduce the frequency and cost of TTC installation; however it often increases the delay and traffic queues (McCoy 1998). Work zone planners need to identify an optimal work zone segment length that strikes an optimal balance between minimizing construction cost and traffic delay. The minimum work zone segment length ($\mathrm{L_{WZ}(min)}$) in this model is specified by the user, while the maximum work zone segment length ($\mathrm{L_{WZ}(max)}$) can be calculated based on the maximum work that can be done in a day $\mathrm{L_{WZ}(max)} = \frac{24-a_1}{a_2}$, where a_1 is the fixed setup time for one work zone segment, and a_2 is the average construction time per kilometer.

6.2.1.2. Start Time (t)

The second decision variable in this model is the construction start time t, which can be any hour of the day from 1 am till midnight. The construction start time t affects both the traffic delay and construction cost. For example, the traditional start of construction in the early morning (e.g., 7 am) and working during regular daytime cause an increase in traffic delays due to the partial or complete lane closures during peak traffic hours. This morning start time, however, requires less cost compared to nighttime work because it does not require additional costs of overtime premiums for construction crews and the costs of nighttime lighting equipment. On the other hand, an evening start time (e.g., 8 pm) and nighttime construction cause the opposite impacts on traffic delays and construction cost. Accordingly, construction start time t is an important decision variable that needs to be optimized to identify an optimal balance between the two critical objectives of minimizing traffic delays and reducing construction cost.

6.2.1.3. Lateral Clearance (LC)

Lateral clearance *LC* is the distance between the work area and the traffic control barriers at the edge of the live lane, as shown in Figure 6.5. This lateral clearance variable can vary from zero meter (no lateral clearance) to any user specified width. Reducing the lateral clearance between the work area and the live lane often causes drivers to reduce their speed and cause longer queue and traffic delays in the work zone area (Highway Capacity Manual (HCM) 2010, Benekohal 2010). On the other hand, increasing the lateral clearance can reduce traffic delays, however, it often requires using part of the shoulder to maintain the required width of the live lane and therefore it causes an increase in the construction costs to prepare the shoulder for traffic use.

6.2.1.4. Shoulder Use (SH)

This decision variable of shoulder use *SH* represents the width of the shoulder in feet that will be resurfaced and/or strengthened for traffic use, as shown in Figure 6.5. The model assumes the existence of a standard 12 feet highway shoulder than can be partially or fully used for traffic. Accordingly, the shoulder use *SH* can vary from 0 (no use) to 12 feet (full use). Using the complete shoulder as an additional lane can significantly reduce traffic delays, however, it requires additional cost to prepare the shoulder for traffic.

6.2.1.5. Access and Egress Method (AE)

The access and egress method *AE* represents the used method to control the entrance and exit of construction vehicles and equipment to and from the work zone. Based on aforementioned field studies and survey results (El-Rayes et al. 2014), four feasible alternatives for the access and egress method variable were identified in the present model. These four alternative methods for controlling the access and egress points in work zones require the use of: flagger, spotter, access ramp, or no access and egress control. Each of these alternative methods can have a different impact on work zone delays and costs and can be defined by the planner in the present model. For example, the impact of these alternative methods on delays and cost were identified during the aforementioned conducted field studies by first measuring the stop time of traffic in the live lanes to allow a safe entry and exit of construction vehicles to and from the work zone. These traffic stop times can then be used to calculate traffic delays using Equations (5) to (9) that will be discussed later in the objective function section. It should be noted that these traffic stop times in Table 1 are used for illustrative purposes and may vary from one highway work zone to another. To ensure that the developed model is generic, it is designed to provide flexibility for planners to specify the traffic stop times that are applicable to their specific highway work zone.

6.3. OBJECTIVE FUNCTIONS

The two main objective functions of this optimization model are to: (1) minimize work zone-related traffic delays, and (2) minimize work zone construction cost. These two main objectives are designed to integrate the impact of all the aforementioned decision variables. The following sections describe the formulation of these two objective functions.

6.3.1. **Minimize Work Zone Delay**

The calculation of the work zone delay in the present model is performed in four main steps that are designed to calculate: (1) actual reduced speed considering speed reduction factors due to work zone parameters U; (2) work zone capacity based on the actual reduced speed CWZ; (3) adjusted wok zone capacity after considering the stopping time of access and egress method CWZA; (4) moving, queue, and total delay for the total duration of the project Td. The performed computations in each of these four steps are briefly discussed in the following sections.

6.3.1.1. Actual Reduced Speed

This step calculates the actual reduced free flow speed at the work zone (U), as show in Equation (6.1) based on the free flow speed at the work zone (FFS) and a number of reductions to consider the impact of work intensity, lane width, lateral clearance, and TTC devices (Benekohal et al 2010, HCM 2010).

$$U = FFS - R_{WI} - R_{LW} - R_{LC} - R_{TTC} \qquad (6.1)$$

Where,

U = Actual reduced free flow speed at the work zone in mph

FFS = Free flow speed assumed to be posted speed limit at work zone+5 mph

R_{WI} = Reduction in FFS due to work intensity in mph

R_{LW} = Reduction in FFS due to lane width *LW* in mph

R_{LC} = Reduction in FFS due to lateral clearance *LC* in mph

R_{TTC} = Reduction in FFS due to additional TTC in mph

6.3.1.2. <u>Work Zone Capacity</u>

The actual work zone capacity C_{WZ} represents the traffic capacity in the work zone area based on the work zone parameters. The work zone capacity is calculated in this step using the models developed by Benekohal (2003 and 2010) and HCM (2010). C_{WZ} is calculated using Equation 2 based on the actual reduced speed of work zone *U* that was calculated in the previous step (see Equation 1) and the number of open lanes N_{lanes}. The heavy vehicle adjustment factor f_{HV} is assumed in this model to be 0.88 (HCM 2000).

$$C_{WZ} = (128.2 * U^{0.6857}) \text{ x Nlanes x } f_{HV} \quad \text{(Vehicle. Hour)} \qquad (6.2)$$

6.3.1.3. <u>Adjusted Work Zone Capacity</u>

This step provides a novel methodology to quantify the impact of the utilized access and egress method on traffic delays. It calculates the adjusted work zone capacity C_{WZA} after considering the impact of access and egress method by first computing the average traffic stopping time T_{AE} per hour that is required to ensure a safe entry and exit of all vehicles to and from the work zone, Equation (6.3). It should be noted that the average traffic stopping time to allow a vehicle to enter t_{ai} and exit t_{ei} the work zone were measured and identified in the aforementioned field studies, as shown in Table 6.1. The calculated average traffic stopping time T_{AE} in Equation (6.3) is then used to calculate the adjusted work zone capacity C_{WZA}, as shown in Equation (6.4).

$$T_{AE} = N_{AE} * (t_{ai} + t_{ei}) \quad \text{(min)} \tag{6.3}$$

$$C_{WZA} = (60 - T_{AE}) * C_{WZ}/60 \quad \text{(Vehicle. Hour)} \tag{6.4}$$

Where,

t_{ai} = Average traffic stopping time per vehicle entering work zone in minutes;

t_{ei} = Average traffic stopping time per vehicle exiting work zone in minutes;

N_{AE} = Average number of vehicles entering or exiting the work zone per hour.

It is worth to mention that access and egress methods as well as delay values are not limited to these values and it is for the user to determine the methods of access and egress and the expected delay per minutes for each method.

Table 6.1 Measured Traffic Stopping Times for Different Access and Egress Methods

Access and Egress Method	Traffic Stopping Time to Enter Work Zone	Traffic Stopping Time to Exit from Work Zone
	(minutes)	(minutes)
AE_1 = Using flagger	$ta_1 = 1.5$	$te_1 = 2.0$
AE_2 = Using spotter	$ta_2 = 1$	$te_2 = 1.2$
AE_3 = Using entrance ramp	$ta_3 = 0.1$	$te_3 = 0.1$
AE_4 = No control method	$ta_4 = 2$	$te_4 = 2$

6.3.1.4. Total Work Zone Delay (T_d)

This step calculates the total work zone delay during the project duration T_d by summing up all the hourly delays t_d, as shown in Equation (6.5). The hourly delay time t_d is equal to summation of the queue delay t_q and the moving delay t_m due to speed reduction, as shown in Equation (6.6). If the approaching hourly traffic volume Q is less than or equal the work zone capacity C_{WZA} then no queue delay will formulate and the delay time t_d will be only equal to the moving delay, as show in Equations (6.6) to (6.9). The hourly traffic flow can be input by the user, as shown in Figure 6.6.

$$T_d = \sum_{t}^{t+D} t_d * N_{WZ} \qquad \text{(Vehicle. Hour)} \qquad (6.5)$$

$$t_d = t_m + t_q \qquad \left(\text{Vehicle.}\frac{\text{Hour}}{\text{Hour}}\right) \qquad (6.6)$$

$$t_d = t_m = \left(\frac{1}{U} - \frac{1}{70}\right) * Q * L_{WZ} \quad \text{If } Q \leq C_{WZA} \qquad \left(\text{Vehicle.}\frac{\text{Hour}}{\text{Hour}}\right) \qquad (6.7)$$

$$t_m = \left(\frac{1}{U} - \frac{1}{70}\right) * Q * L_{WZ} \quad \text{if } Q > C_{WZA} \qquad \left(\text{Vehicle.}\frac{\text{Hour}}{\text{Hour}}\right) \qquad (6.8)$$

$$t_q = 0.5 * \left(1 + \frac{(Q - C_{WZA})}{(C_o - Q)}\right) * (Q - C_{WZA}) \quad \text{if } Q > C_{WZA} \qquad \left(\text{Vehicle.}\frac{\text{Hour}}{\text{Hour}}\right) \qquad (6.9)$$

Where,

t_d = Traffic delay during hour d, which is calculated using Equations (6.6) to (6.9)

t = Hour of construction start time

D = Duration in hours to complete a work zone segment ($D = a_1 + (a_2\, x\, L_{WZ})$)

a_1 = Fixed setup time in hours

a_2 = Construction time to complete one mile

C_o = Free flow capacity of a highway without a work zone

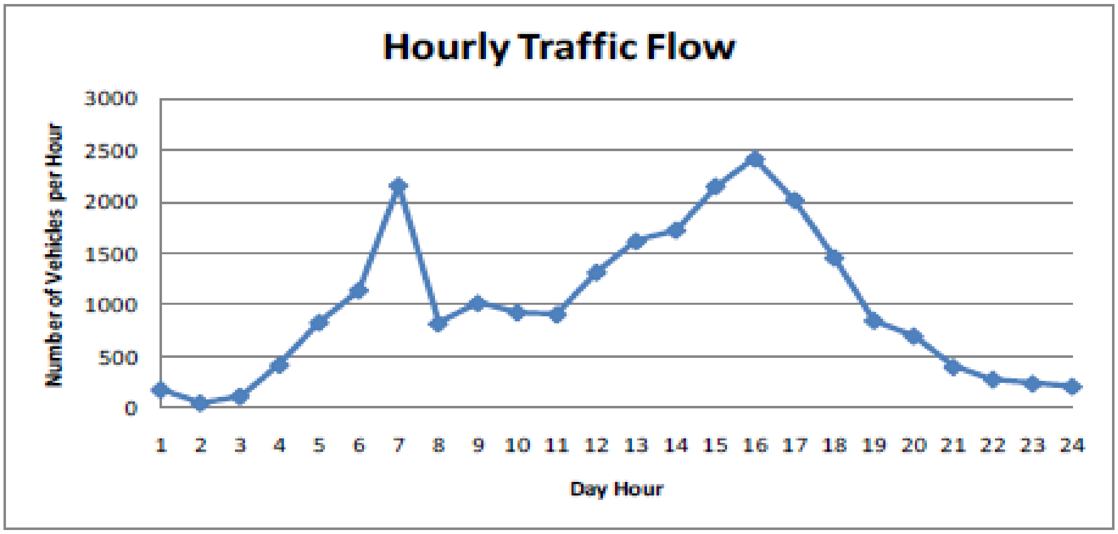


Figure 6.6. Example of Hourly Traffic Flow

6.3.2. Minimize Work Zone Construction Cost

The work zone construction cost in this model is designed to include: (1) cost of setup, removal, and relocating traffic control devices C_{TC}; (2) overtime cost of construction crews C_{OT}; (3) cost of nighttime lighting equipment C_{NT}; (4) cost of access and egress points control C_{AE}; and (5) cost of preparing the shoulder for partial or full traffic use C_{SH}, as shown in Equation (6.10). Each of these five costs is explained in the following sections.

$$\text{Min Work Zone Construction Cost} = C_{HC} + C_{OT} + C_{NT} + C_{AE} + C_{SH} + C_{TC} \quad (6.10)$$

6.3.2.1. <u>Highway Construction Cost (C_{HC})</u>

The highway construction cost C_{HC} represents the total cost of highway construction activities for the entire project during regular working hours without considering the additional work zone layout costs listed in Equation (10) such as overtime cost and nighttime lighting cost. The highway construction cost C_{HC} is calculated in the present model using Equation (6.11).

$C_{HC} = C_C * L_{WZ} * N_{WZ}$ (6.11)

Where,

C_C = Average regular construction cost in $ per kilometer.

6.3.2.2. <u>Overtime Cost (C_{OT})</u>

The overtime cost (C_{OT}) represents the additional costs that accounts for overtime labor wages, additional overhead costs, and reduced worker productivity during overtime hours. The overtime cost is calculated in the present model using Equation (6.12).

$C_{OT} = C_T * C_C * L_{WZ} * N_{WZ}$ (6.12)

Where,

C_T = Hourly cost factor for overtime premiums of construction crews, as shown in Table 8.

Table 6.2. Example of Hourly Cost Factors for Overtime Premiums

Working Time (t)	Overtime Factor C_T
6:00 am to 4:00 pm	1.0
4:00 pm to 8:00 pm	1.25
8:00 pm to 6:00 am	1.5

6.3.2.3. <u>Nighttime Cost (C_{NT})</u>

The nighttime cost (C_{NT}) represents the additional costs of utilizing nighttime lighting equipment and nighttime safety devices. The nighttime cost is calculated in the present model using Equation (6.13).

$C_{NT} = C_N * C_C * L_{WZ} * N_{WZ}$ (6.13)

Where,

C_N = Cost factor for nighttime lighting and safety equipment, as shown in Table 3.

Table 6.3. Example of Additional Nighttime Cost Factor

Working Time (t)	Nighttime Factor C_{NT}
6:00 am to 6:00 pm	1.0
6:00 pm to 6:00 am	1.15

6.3.2.4. <u>Access and Egress Method Cost (C_{AE})</u>

The cost of access and egress method C_{AE} represents the additional cost for controlling the work zone access and egress points per kilometer. Examples of this cost include (a) the cost of using flagger/s to control traffic at the access and egress points, and/or (b) the cost of constructing an access ramp to the work zone, as shown in Table 6.4. The access and egress method cost is calculated in the present model using Equation (6.14).

$$C_{AE} = C_{AEM} * C_C * L_{WZ} * N_{WZ} \quad (6.14)$$

Where,

C_{AEM} = Cost factor for access and egress method, as shown in Table 10.

Table 6.4. Example of Impacts of Access and Egress Methods on Cost

Access and Egress Method	Cost Factor of Access and Egress Method C_{AEM}
Using flagger	1.02
Using spotter	1.01
Using entrance ramp	1.06
No control method	1

6.3.2.5. Shoulder Use Cost (C_{SH})

The shoulder use cost (C_{SH}) represents the required costs to prepare the shoulder for partial or full traffic use, as shown in Equation (6.15).

$$C_{SH} = C_{Shi} + (C_{ShR} * SH * L_T) \qquad \text{if SH is} > 0$$

$$C_{SH} = 0 \qquad \text{if SH is} = 0 \qquad (6.15)$$

Where,

C_{Shi} = Fixed mobilization cost to start work on the shoulder in $

C_{ShR} = Cost of preparing one meter of shoulder width for traffic in $ per kilometer

L_T = Total length of the project in kilometers.

6.3.2.6. Traffic Control Cost (C_{TC})

$$C_{TC} = C_{TD} + C_I + C_{REL} + C_{REM} \qquad (6.16)$$

Where,

C_{TD} = Cost of using/renting traffic control devices in $;

C_I = Cost of installing traffic control devices in $;

C_{REL} = Cost of relocating traffic control devices in $; and

C_{REM} = Cost of removing traffic control devices in $.

Cost of Using Traffic Control Devices (C_{TD}):

The cost of using traffic control devices C_{TD} represents the cost of using or renting traffic control devices. This cost accounts for (a) the cost of devices in the warning, advanced, and termination areas C_{TDi} which is independent from the work zone segment length; and (b) the cost of devices in the work area C_{TDl} which is dependent on the work zone segment length, as shown in Equation (6.17).

$$C_{TD} = [C_{TDi} + (C_{TDw} * L_{WZ})] * N_{WZ} \quad (6.17)$$

Where,

C_{TDi} = Daily cost of using/renting traffic control devices in the warning, advanced, and termination areas in $ per work zone; and

C_{TDw} = Daily cost of using/renting traffic control in the work area in $ per kilometer.

Installation Cost (CI) is the initial transportation and installation cost of traffic control devices at the beginning of the project. The cost of installing these devices in the warning, advanced, and termination areas is independent from the work zone segment length, while the installation cost of these devices in the work area depends on the work zone segment length, as shown in Equation (6.18).

$$CI = CIi + (CIw * LWZ) \quad (6.18)$$

Where,

C_{Ii} = Cost of installing traffic control devices in the warning, advanced, and termination areas in $ per work zone; and

C_{Iw} = Cost of installing traffic control devices in the work zone area in $ per kilometer.

<u>Relocating Cost after Each Work Zone (C_{REL})</u> is the cost of relocating traffic control devices after the completion of work in each work zone segment length segment until all segments are completed (McCoy 1998). The total relocating cost is dependent on the number of work zones NWZ, as shown in Equation (6.19).

$$C_{REL} = [C_{RELi} + (C_{RELw} * L_{WZ})] * N_{WZ} \qquad (6.19)$$

Where,

C_{RELi} = Cost of relocating traffic control devices in the warning, advanced, and termination areas in $ per work zone;

C_{RELw} = Cost of relocating traffic control devices in the work area in $ per kilometer.

<u>Removing Cost after Last Work Zone (C_{REM})</u> is the cost of the final removal of traffic control devices after the last work zone segment, and is calculated, as shown in Equation (6.20).

$$C_{REM} = C_{REMi} + (C_{REMw} * L_{WZ}) \qquad (6.20)$$

C_{REMi} = Cost of removing traffic control devices in the warning, advanced, and termination areas in $ per work zone; and

C_{REMw} = Cost of removing traffic control devices in the work area in $ per kilometer

6.4. CONSTRAINTS

The model is designed to consider all relevant practical constraints that specify the lower and upper boundaries of work zone length, starting time, lane width, shoulder use, and lateral clearance, as shown in Table 6.5.

Table 6.5. List of Optimization Model Constraints

Constraints	Minimum	Maximum
Work Zone Segment Length (L_{WZ})	User specified	$L_{WZ}(\max) = \frac{24 - a_1}{a_2}$
Starting Time (t)	1 AM	12 AM
Lane width (LW)	2.44 m (8 ft.)	3.6 m (12 ft.)
Shoulder Use (SH)	0	User specified
Lateral Clearance (LC)	0	User specified

6.5. IMPLEMENTATION PHASE

The main purpose of this phase is to implement the formulated model to enable the optimization of work zone layout parameters and the identification of optimal tradeoffs between minimizing traffic delays and construction cost. The model is implemented using a Non-Dominated Sorting Genetic Algorithm (NSGA2) to perform the optimization computation of the aforementioned multi-objective optimization problem because of the NSGA2 capabilities of generating optimal tradeoffs among all objectives in a single run; and its use of an elitist strategy that prevents the loss of optimal solutions once they are found (Deb et al. 2000). NSGA2 adopts the survival of the fittest approach in addition to the concept of Pareto optimality in order to converge to a set of non-dominated optimal solutions that represent various tradeoffs among the optimization objectives (Zitzler and Thiele 1999; Deb et al. 2000). NSGA2 has been successfully utilized to support multiobjective optimization in other construction decision making problems such as time-cost tradeoff analysis and optimizing the utilization of lighting equipment in nighttime highway construction (El-Rayes and Hyari 2005; Hyari and El-Rayes 2006; El-Anwar et al. 2008; Khlafallah and El-Rayes 2006; El-Rayes and Kandil 2005; Kandil and El-Rayes 2006a, 2006b; Kandil et al. 2010; Orabi et al. 2010; Heon Jun and El-Rayes 2011; Senouci and El-Rayes 2009; Said and EL-Rayes 2011).

The NSGA2 computations in this model are performed in four main tasks: (1) an initialization task that creates an initial population of randomly generated layout parameters solutions for the problem; (2) a fitness evaluation task that calculates the values of cost and delay for each of the generated solutions; (3) a ranking task that ranks the generated solutions based on non-domination criteria (Deb et al. 2000); and (4) a generation evolution task that creates new populations of solutions using the genetic algorithm operations of selection, crossover, and mutation (El-Rayes and Kandil 2005). This process is repeated until the defined number of generations achieved.

To ensure that the developed model is generic and applicable to a wide range of highway work zones, it is designed to provide decision makers with the flexibility to define the specific parameters of their project and work zone, including: (1) the lower and upper boundaries of the model decision variables and constrains including work zone length, construction start time, lane width, shoulder use, and lateral clearance, as shown in Table 6.5; (2) the general work zone data such as posted work zone speed limit, fixed setup time for one work zone segment, average construction time per kilometer, total length of project, number of trucks entering work zone, and free flow capacity of highway without work zone, as shown in Table 6; (3) the work zone cost data such as average construction cost per kilometer, cost of preparing one meter of shoulder width for traffic per kilometer, and hourly cost factors for overtime premiums, as shown in Table 7; and (4) the hourly traffic flow data, as shown in Figure 6.6.

6.6. PERFORMANCE EVALUATION PHASE

An application example is analyzed to evaluate the performance of the model and demonstrate its capabilities in optimizing work zone layout parameters. The example focuses on optimizing the work zone layout for resurfacing the pavement of a 16.1 km (10-mile) stretch of an existing highway that has a speed limit of 110 km/h (70 mph). The existing highway has two lanes and two standard shoulders with a width of 3.6 meter (12 feet) each. The work zone requires full closure of one lane and one shoulder while keeping the other lane and shoulder open for traffic. The work zone has a posted speed limit of 90 km/h (55 mph) and its minimum segment length LWZ (min) is assumed to be 0.8 km (0.5 mile) per day. The required input that construction planners need to provide for this application example include work zone cost data as shown Table 6.6; general work zone data as shown in Table 6.7; and the hourly traffic flow data as shown in Figure 6.6.

Table 6.6. Work Zone Cost Data

Input Data	Description	Cost
C_{TDi}	Daily cost of using/renting traffic control devices in the warning, advanced, and termination areas per work zone	\$2,000
C_{TDw}	Daily cost of using/renting traffic control in the work area per kilometer	\$621
C_{Ii}	Cost of installing traffic control devices in the warning, advanced, and termination areas per work zone	\$1,000
C_{Iw}	Cost of installing traffic control devices in the work zone area per kilometer	\$621
C_{RELi}	Cost of relocating traffic control devices in the warning, advanced, and termination areas per work zone	\$1,000
C_{RELw}	Cost of relocating traffic control devices in the work area per kilometer	\$621
C_{REMi}	Cost of removing traffic control devices in the warning, advanced, and termination areas per work zone	\$1,000
C_{REMw}	Cost of removing traffic control devices in the work e area per kilometer	\$621
C_C	Average construction cost per kilometer	\$621,00
C_{Shi}	Fixed mobilization cost to start work on the shoulder	\$5,000
C_{ShR}	Cost of preparing 0.304 meter (one feet) of shoulder width for traffic per kilometer	\$3,105
C_T	Hourly cost factors for overtime premiums	See Table 6.2
C_N	Additional nighttime cost factors	See Table 6.3

Table 6.7. General Work Zone Data

Input Data	Description	Value
SL	Posted work zone speed limit	88 km/h (55 mph)
a_1	Fixed setup time for one work zone segment	2 hour
a_2	Average construction time	3.75 hour/km (6 hour/mile)
L_T	Total Length of project	16.1 km (10 miles)
N_{AE}	Number of trucks entering work zone	3 per hour
C_o	Free flow capacity of highway without work zone	2500 veh.hr

The developed model is used to optimize the work zone layout of this application example in order to generate and analyze optimal tradeoffs between the two important objectives of minimizing traffic delays and minimizing construction costs. The model is used to search for and identify a wide range of Pareto-optimal (i.e., non-dominated) solutions where each provides a unique and optimal tradeoff between the two objectives, as shown in Figure 6.7. Each of these optimal tradeoffs can be achieved by implementing an optimal configuration of the work zone layout that specifies the optimal work zone segment length, construction start time, lateral clearance, shoulder use width, and access and aggress method. It should be noted that the shape of the Pareto optimal front and the number of its solutions varies from one case study to another as shown in Figure 6.9 that was generated by the present model for another case study of a work zone that requires closure of one lane on an existing highway with four lanes for a stretch of 5 miles.

The generated Pareto-optimal solutions for this application example cover a wide spectrum of trade-offs that range from solution 1 which represents the minimum work zone traffic delay to solution 2 that provides the minimum construction cost, as shown in Figure 6.7. Solution 1 was able to minimize work zone traffic delay to only 58 Vehicle Hour by (1) minimizing the work zone segment length L_{WZ} to its minimum value ($\mathrm{L_{WZ}(min)} =$ 0.8 km/0.5 mile) to reduce the queue length of traffic in the work zone area; (2) starting the work at 11 pm to perform the construction operations during the low traffic hours of nighttime; (3) using flagger to control access and egress points to minimize the traffic stopping time caused by vehicles entering and exiting the work zone; (4) providing the maximum lateral clearance of 1.8 meter (6 feet) to minimize work intensity and its negative impact on reducing the traffic speed; and (5) using 1.8 meter (6 feet) of the shoulder for regular traffic to maintain a lane width of 3.6 meter (12 feet) and avoid speed reduction due to lane narrowing. Despite the effectiveness of these decisions to minimize traffic delay, they resulted in the highest cost of work zone construction ($2.79 Million) among the generated optimal tradeoffs in Figure 6.7. This maximum construction cost of solution 1 was caused by an increase in the cost of (1) work zone setup and traffic control due to using the maximum number of work zone segments that resulted from selecting the minimum length of work zone segment; (2) nighttime lighting equipment and labor overtime premiums due to starting the work at 11 pm; (3) flagger use to control work zone access and egress points; and (4) preparing 1.8 meter (6 feet) of the shoulder for traffic use, as shown in Table 6.8.

Solution 2, on the other end of the spectrum (see Figure 6.7), was able to minimize the construction cost to only $1.056 Million by (1) minimizing work zone setup and traffic control costs due to the selection of the maximum work zone segment length $\mathrm{L_{WZ}(max)}$ of 2.41 km (1.498 mile); (2) reducing nighttime construction cost and labor overtime costs as a result of starting the work at 6:00 am and performing the work during the regular daytime shift; (3) eliminating the cost of work zone access and egress control as a results of not using any control method; and (4) avoiding shoulder use cost as a result of not using any part of the shoulder and not using lateral clearance. Despite the lower cost of these optimal decisions, they resulted in the highest traffic delay (82,443 Veh. Hr) among the generated optimal tradeoffs due to (1) the selection of the maximum length of work zone segments; (2) the execution of the work during the highest traffic demand periods of the day; (3) the lack of an access and egress control method; and

(4) the lack of lateral clearance between the work zone and live lane, as shown in Table 6.8.

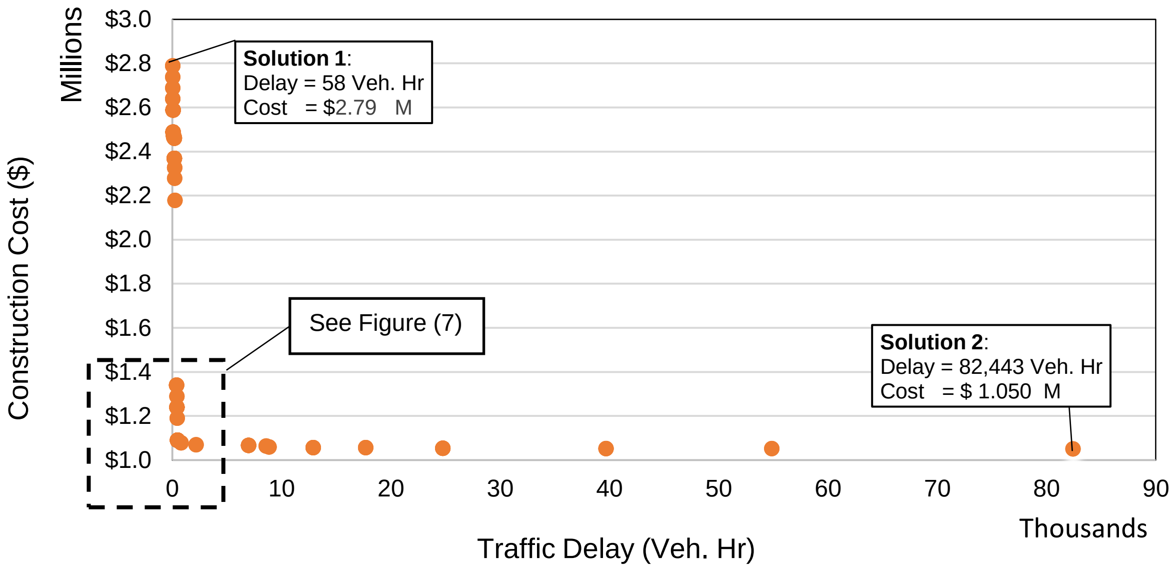


Figure 6.7. Optimal Tradeoffs between Work Zone Traffic Delay and Construction Cost

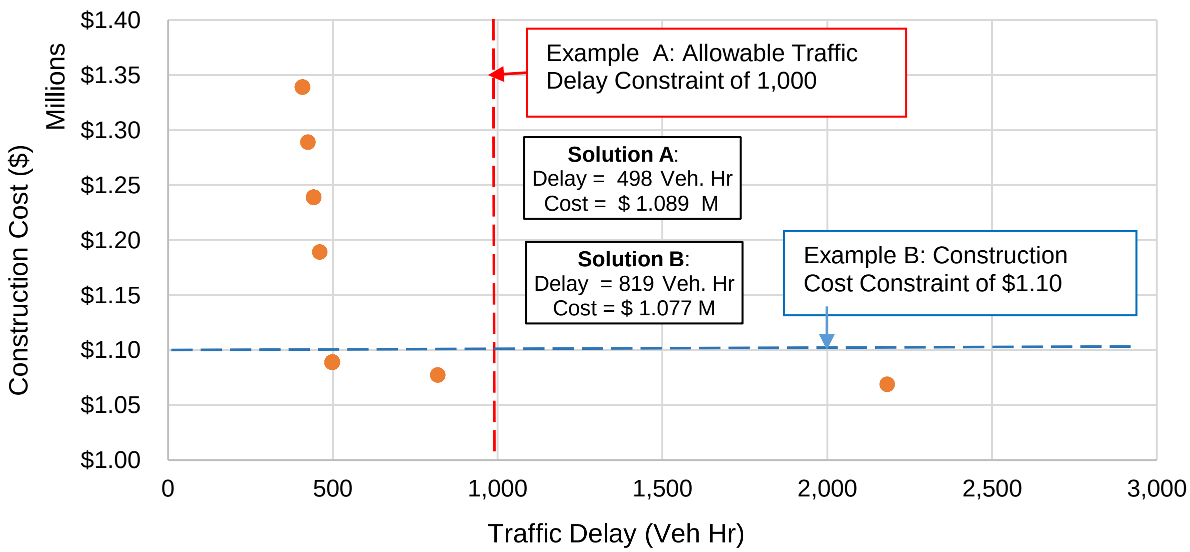


Figure 6.8. Subset of Generated Optimal Tradeoffs

Table 6.8. Optimal Work Zone Layout Decisions for Sample Solutions

Decision Variable	Solution 1	Solution A	Solution B	Solution 2
Work Zone Segment Length (L_{WZ})	0.81 km (0.5 *mile)*	0.81 km (0.5 mile)	1,066 km (0.666 mile)	2,411 km (1.498 mile)
Construction Start Time (t)	11 PM	8 AM	8 AM	6 AM
Access and Egress Method (AE)	Flagger	Spotter	Access Ramp	No Control
Lateral Clearance (LC)	1.83 m (6 *ft)*	0	0	0
Shoulder Replacement (SH)	1.83 m (6 *ft)*	0	0	0
Traffic Delay (Veh.Hr.)	**58**	**498**	**819**	**82,443**
Construction Cost ($)	**$ 2.79M**	**$1.093 M**	**$1.077 M**	**$ 1.050M**

In addition to the aforementioned extreme solutions 1 and 2, the model was able to generate a wide range of optimal tradeoffs between construction cost and traffic delay, as shown in Figure 6.7. A decision maker can analyze these optimal tradeoffs and select a tradeoff that satisfies the specific priorities and/or constraints of the project. For example, a decision maker can analyze the generated optimal tradeoffs in Figure 6.7 and Figure 6.8 and select an optimal solution that provides (a) the least traffic delay that can be achieved within a specified budget for the construction cost; and/or (b) the least work zone cost that complies with a specified maximum allowable traffic delay constraint. For example, if the project has a construction cost constraint of $1.1 Million, then solution A should be selected since it causes the least traffic delay of 499 Veh.Hr while complying with this budget constraint. Similarly, if the project has a maximum allowable traffic delay constraint of 1,000 Veh.Hr, then solution B should be selected because it provides the least work zone cost of $1.077 Million that can be achieved while complying with this constraint. The optimal work zone layout decisions for both solutions A and B are summarized in Table 6.8.

The results of this analysis illustrate the unique and novel capabilities of the developed model in generating a wide spectrum of Pareto-optimal solutions, where each identifies an optimal work zone layout that provides a unique and optimal trade-off between the two critical optimization objectives of the model. It should be noted that the shape of the Pareto front and the number of its solutions varies from one case study to another as shown in Figure 6.9 that was generated by the present model for another case study. This case study was for a four lanes highway with one single lane closure and a total length of 5 miles. These new and novel capabilities are expected to improve existing practices for designing highway work zones and can lead to improved traffic mobility and reduced construction cost. This should prove useful to both decision makers in the highway construction industry and highway road users.

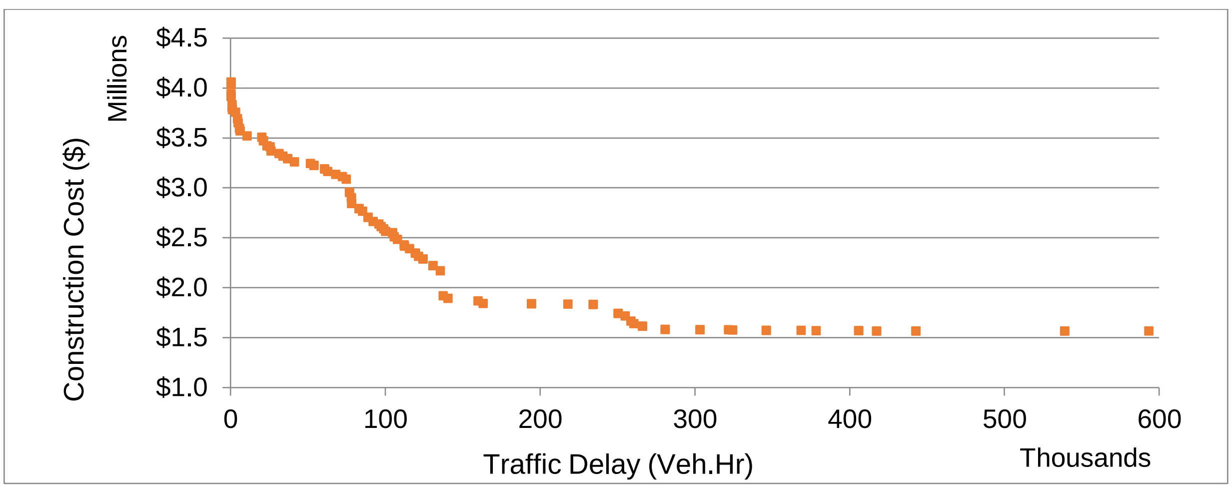


Figure 6.9. Optimal Tradeoffs between Work Zone Traffic Delay and Construction Cost for Four Lanes Case Study

6.7. CONCLUSIONS

A novel multi-objective optimization model was developed to generate optimal trade-offs between the two conflicting work zone layout objectives of minimizing traffic delay and construction cost. The model was designed to optimize work zone layout parameters including work zone segment length, construction start time, lateral clearance, shoulder use, and work zone access and egress method. The performance of the developed model was evaluated by optimizing the highway work zone layout of a pavement-resurfacing project. The results of this analysis illustrated the unique capabilities of the model in generating a wide spectrum of Pareto-optimal solutions, where each identifies an optimal work zone layout that provides a unique and optimal trade-off between the two optimization objectives of minimizing traffic delay and construction cost. At one end of the generated spectrum, the minimum traffic delay solution was achieved by minimizing the work zone segment length, starting construction work at night, using flagger to control access and egress, providing maximum lateral clearance, and using 1.8 meter (6 feet) of the shoulder for temporary traffic use. At the other end of the spectrum, the minimum construction cost solution was achieved by maximizing work zone segment length, and performing work during regular daytime hours without the use of lateral clearance, shoulder, nor access and egress control method. In addition to these two extreme solutions, the model was able to generate a wide range of optimal tradeoffs between construction cost and traffic delay that can be used by decision makers to select an optimal tradeoff that satisfies the specific priorities and/or constraints of the project. These new and novel capabilities are expected to improve existing practices for designing highway work zone layouts and can lead to improved traffic mobility and reduced construction cost. The primary contributions of this research to the body of knowledge include the development of (1) an original and comprehensive set of metrics for measuring and quantifying the impact of the important work zone layout parameters of shoulder use, lateral clearance, and work zone access and egress method on traffic delays and construction cost; and (2) a novel multi-objective optimization methodology for generating and analyzing optimal tradeoffs between the two critical work zone layout objectives of minimizing traffic delays and construction cost.

CHAPTER 7

Optimizing the Planning of Highway Work Zones to Maximize Safety and Mobility

7.1. INTRODUCTION

This chapter presents the development of a novel multi-objective optimization model for work zone layouts that is capable of generating optimal tradeoffs between maximizing work zone safety and maximizing traffic mobility. The model is designed to identify optimal solutions for the important work zone planning parameters of speed limit, work zone segment length, construction start time, shoulder use, lateral clearance, temporary traffic control measures, and work zone access and egress method. The optimization model is developed in four main phases: (1) decision variables phase that identifies all relevant work zone layout variables that affect both the safety and mobility of highway work zones; (2) objective functions phase that formulates two objective functions that quantify and optimize the impact of all the identified work zone decision variables on work zone safety and traffic mobility; (3) constraints phase that models all relevant and practical constraints that affect this optimization problem; and (4) implementation phase that performs the model optimization computations using multi-objective genetic algorithms and specifies the model input and output, as shown in Figure 7.1. The following sections describe these four development phases and analyze an application example to illustrate the use of the optimization model and demonstrate its unique and novel capabilities.

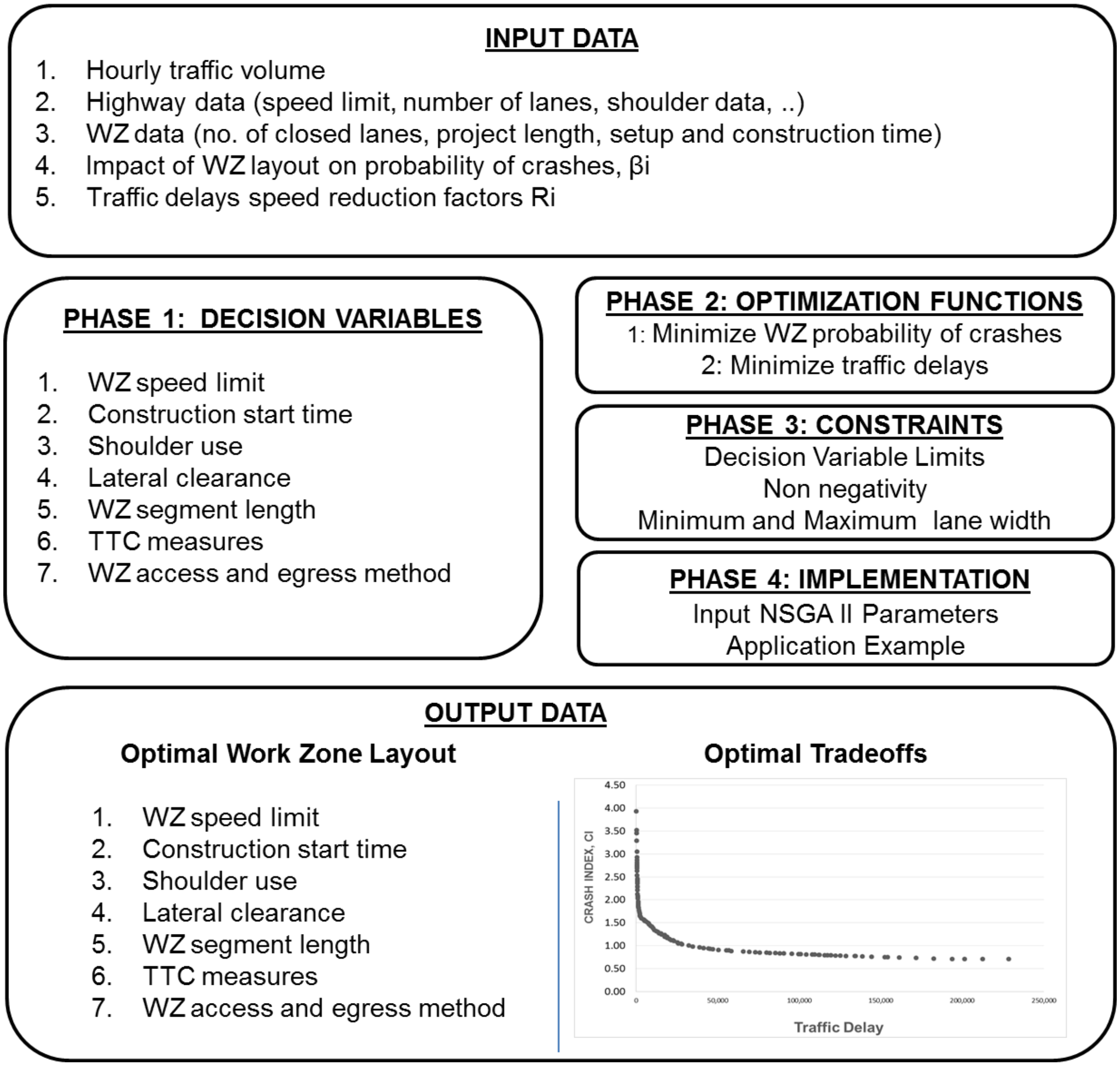


Figure 7.1. Model Development Phases

7.2. DECISION VARIABLES PHASE

The purpose of this phase is to identify all work zone decision variables that affect safety and mobility based on the findings of a comprehensive literature review and two national surveys. First, a number of existing studies in the literature have reported that work zone speed limit, work zone segment length, construction start time, lateral clearance and shoulder use have an impact on safety and mobility (Benekohal 2010, Du and Chien 2014, Fei and Zhu 2016, Jiang and Adeli 2003, McCoy 1998, El-Ghamraway

2010, El-Rayes et al. 2010). Second, two online surveys were conducted to gather feedback from DOT resident engineers and highway contractors on the effectiveness of various work zone layout parameters on safety and mobility (El-Rayes et al. 2014 and El-Rayes et al. 2010). In these surveys, respondents reported that the work zone parameters that had the greatest effectiveness in improving safety and mobility included work zone layout, speed limit, vision obstruction, reduced lane width, work zone hours, work zone duration, use of right-side or median shoulder as a temporary traffic lane, and access and egress control methods (El-Rayes et al. 2014 and El-Rayes et al. 2010). Accordingly, the identified decision variables in this model are (1) posted speed limit; (2) construction start time; (3) lateral clearance; (4) shoulder use; (5) work zone segment length; (6) temporary traffic control device; and (7) access and aggress method, as shown in Figure 7.1. The following sections provide a concise description of each of these variables and their impact on work zone mobility and cost.

7.2.1. Work Zone Speed Limit (SL)

The first decision variable in this model is the posted speed limit *SL* in the area of the work zone in Kilometers per Hour (km/h). The work zone speed limit is the reduced posted speed limit from the original highway speed limit in the part of the temporary traffic control of the highway where road conditions are changed because of a work zone (MUTCD 2009). Reducing the posted work zone speed limit is reported to improve work zone safety (Bai and Li 2006, Sommers and McAvoy 2013) and reduce the mobility of motorists in the work zone area (Fei and Zhu 2016, Benekohal 2010, Hajbabaie et al 2015). Work zone planners need to identify and specify a work zone speed limit that strikes an optimal balance between these conflicting safety and mobility goals. Accordingly, the work zone speed limit (SL) is an important decision variable in this model and it can range from a minimum speed limit $SL(min)$ that is specified by the planner and has a default value of 55 km/h (35 mph) to a maximum speed limit $SL(max)$ which is assumed to be the regular speed limit of the highway before the work zone.

7.2.2. Construction Start Time (t)

The second decision variable in this model is the construction start time *t*, which can be any hour of the day from 1 am until midnight. The construction start time *t* affects both the mobility and safety of work zone. For example, planning the construction operations to start in the evening (see Figure 7.3) is reported to improve traffic mobility because of the reduced traffic volumes during the off-peak nighttime hours (Meng and Weng 2013). This late construction start time, however, is reported to increase safety risks due to the inadequate lighting conditions during nighttime hours (Ullman et al 2008, Shepard and Cottrell 1985, Hancher and Taylor 2001, El-Rayes and Hyari 2005, El-Rayes et al 2009). On the other hand, a morning start time and daytime construction is reported to cause the opposite impacts on traffic delays and work zone hazards (Meng and Weng 2013, Elghamraway 2010). Accordingly, construction start time t is an important decision variable that needs to be optimized to identify an optimal balance between the two critical objectives of minimizing the probability of crashes and minimizing traffic delays.

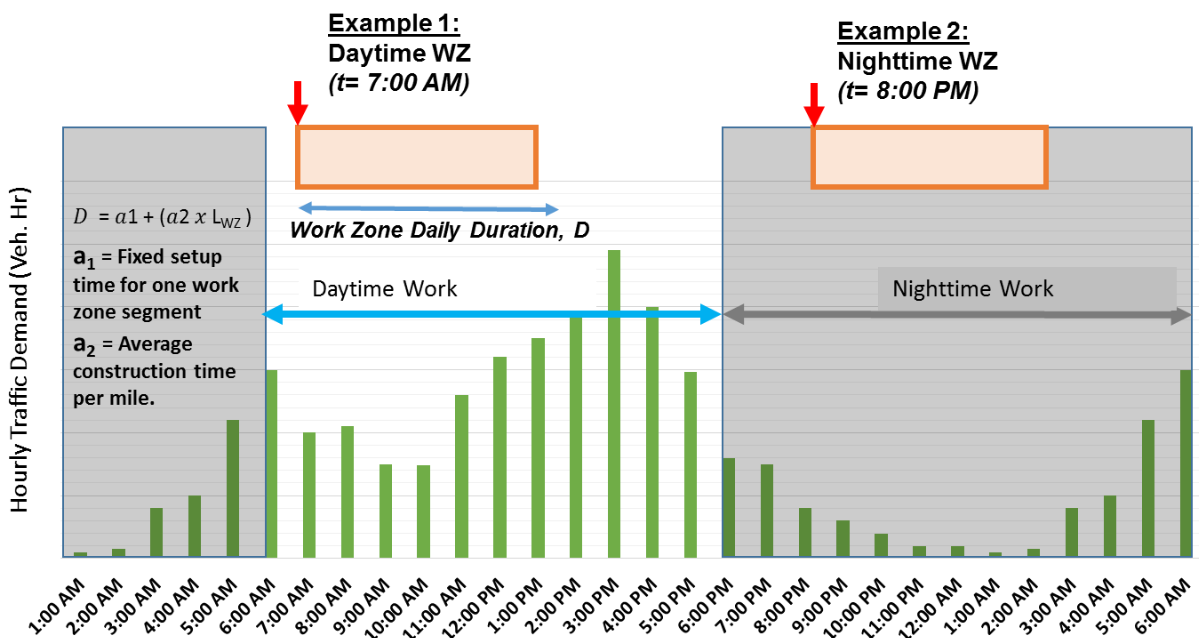
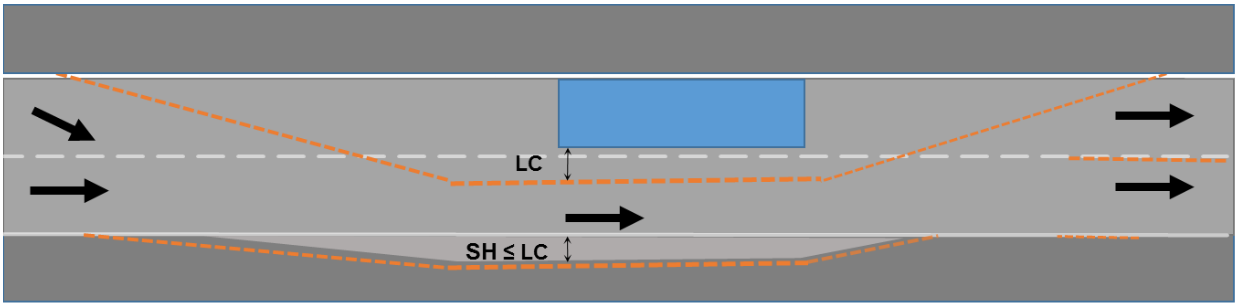


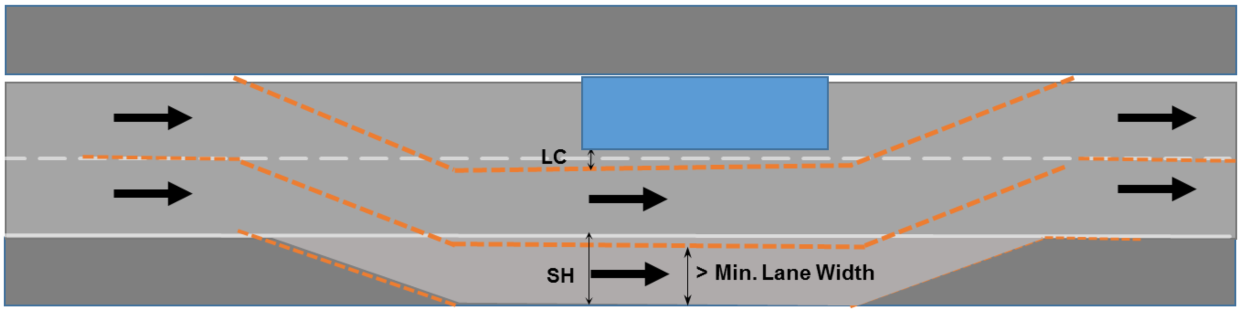
Figure 7.2. Impact of Construction Start Time (T) On Daytime and Nighttime Work

7.2.3. Shoulder Use (SH)

The third decision variable is shoulder use *SH* which represents the width of the shoulder in meter that will be resurfaced and/or strengthened for traffic use, (see Figure 7.4). The model enables planners to specify existing highway shoulder width that can be partially or fully used for traffic. Accordingly, the shoulder use variable *SH* can vary from 0 (no use) to complete width of the shoulder (full use), as shown in Figure 7.3. The temporary use of the shoulder to provide wider lane width or the full use of shoulder as an extra traffic lane is reported to improve traffic mobility (Du and Chein 2014). This partial or complete use of the shoulder, however, has negative impacts on safety because reducing or eliminating an existing shoulder width is reported to increase the probability and severity of crashes (Pitale and Shankwitz 2011).



Partial use of shoulder to provide lateral clearance



Full use of shoulder to add another lane

Figure 7.3 Partial and Full Use of Shoulder in the Work Zone Area

Figure 7.4 Partial Use of Shoulder for Traffic in A Highway Work Zone

7.2.4. Lateral Clearance (LC)

The fourth decision variable is the Lateral clearance *LC*, which represents is the distance between the work area and the traffic control barriers at the edge of the live lane, as shown in Figure 7.5*.* The range of the lateral clearance variable in this model (i.e., minimum and maximum values) can be specified by the planner to comply with the state DOT regulations and requirements. Increasing the lateral clearance distance will provide safer conditions for workers and motorists as it expands the separation distance between the work zone and the active traffic. This increase in lateral clearance can also improve traffic mobility only if it does not cause a reduction in the width of open lanes because increasing the separation distance between traffic and the work area is reported to improve traffic mobility (HCM 2000, Benekohal 2010). In most work zones, however, this increase in lateral clearance reduces the total width of open lanes, which is reported to cause reduction in traffic speed, longer queues, and traffic delay in the work zone area (HCM 2000, Benekohal 2010).

Figure 7.5. Absence of Lateral Clearance during Work Zone Installation

7.2.5. Work Space Segment Length (L_{WS})

The fifth decision variable in this model is the length of a typical segment of work space in kilometers L_{WS}, as shown in Figure 7.6. The minimum work space segment length ($L_{WS}(\min)$) is specified by the user, while the maximum work space segment length ($L_{WS}(\max)$) is the maximum work that can be done in a 24-hour work day $L_{WS}(\max) = \frac{24-a_1}{a_2}$, where a_1 is the fixed setup time for one work space segment, and a_2 is the average construction time in hours per kilometer (Chien et al 2001). The total length of the work zone area L_{WZ} is defined in this model as the daily total disruption length of the highway due to the work zone that includes the length of the shoulder taper, transition area, work space segment L_{WS}, buffer spaces before and after the work space, and downstream taper (MUTCD 2009), as shown in Figure 7.6.

The length of the workspace segment L_{WS} has an impact on work zone safety and traffic mobility. The impact of L_{WS} on safety can be illustrated using Figure 7.7 that shows that the selection of a shorter work zone segment length increases the total number of segments or days to finish the project which increases the overall length of all the project work zones L_{TWZ}. This longer overall length of all the project work zones L_{TWZ} increases the probability of crashes due to the greater interrupted length of the highway by the work zone as shown in Figure 7.7. In addition, shorter work zone segments were reported to increase safety hazards because they require more installation and moving of the daily work zone setups (McCoy 1998). The impact of L_{WS} on mobility was investigated by a number of studies that reported that shorter L_{WS} improve traffic mobility because the use of longer L_{WS} increases traffic delays and queue lengths in the work zone area (Fei and Zhu 2016, Benekohal 2010). Accordingly, planners need to identify an optimal work zone segment length that strikes an optimal balance between maximizing work zone safety and minimizing traffic delay.

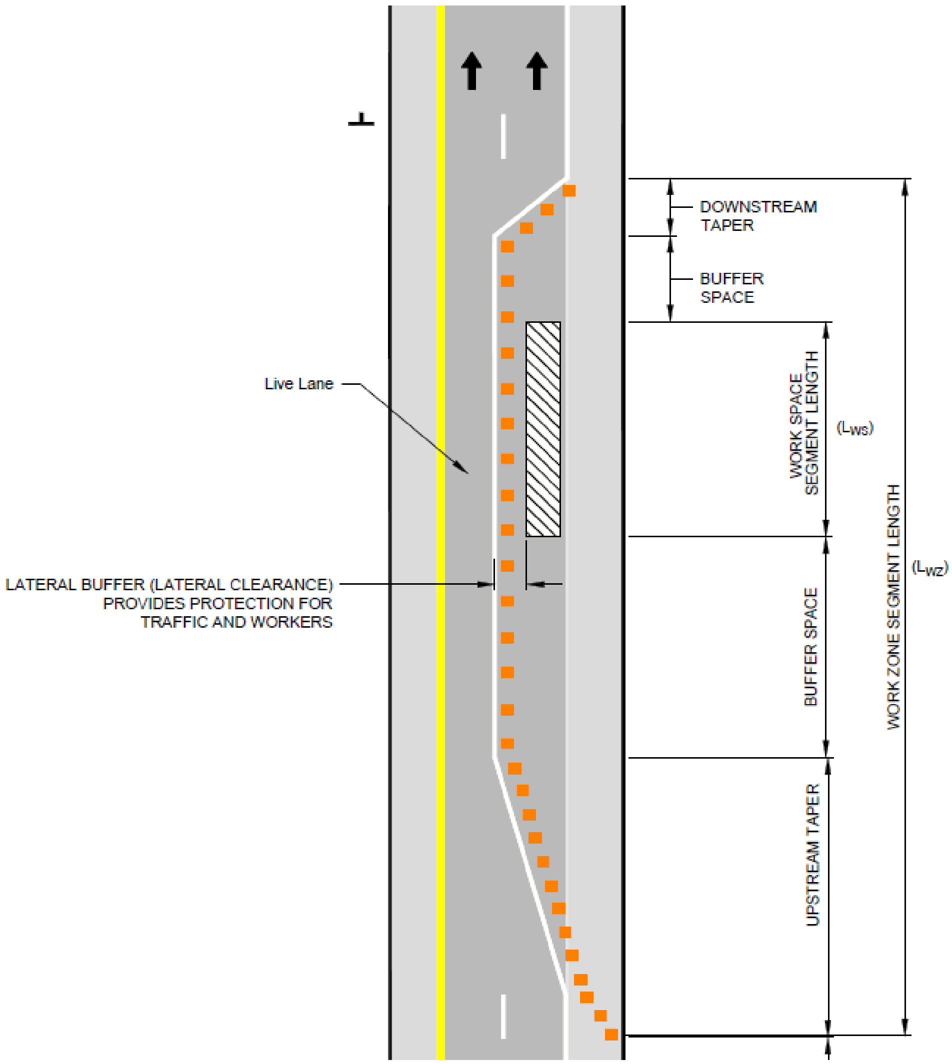


Figure 7.6. Work Zone Layout (MUTCD 2009)

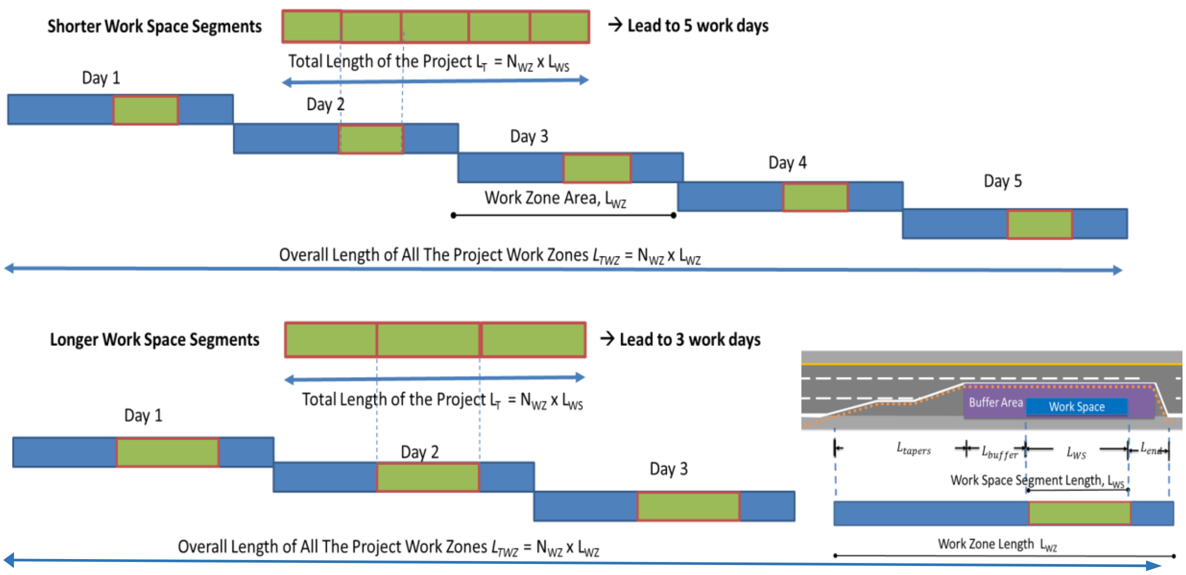


Figure 7.7. Effect of Work Zone Segment Length on the Total Work Area

7.2.6. Temporary Traffic Control Method (TTC)

The use of various combinations of temporary traffic control (TTC) measures in the work zone is represented in this model using six binary decision variables that represent the use of flagger, police patrol, speed photo enforcement, speed monitoring display, radar drone, and portable changeable message signs. The impact of these six TTC measures on traffic mobility and work zone safety is quantified in this model based on (a) field measurements, (b) recently conducted national surveys of state DOTs, and (c) the findings of other research studies (Benekohal et al. 2010, Elghamraway, 2011, Ullman et al 2009). Each type of TTC method has an effect on both safety and mobility at the work zone area. For example, using police patrol and/or flaggers has a strong effect on reducing probability of crashes while causing significant reduction of speed below the posted speed limit, which reduces traffic mobility (El-Rayes et al 2010). This decision variable was modeled as a binary variable to enable the model to search for and identify an optimal set of TTC measures that improves both safety and mobility.

7.2.7. Access and Egress Method (AE)

The access and egress method *AE* represents the used method to control the entrance and exit of construction vehicles and equipment to and from the work zone. Based on aforementioned field studies and survey feedback from DOT personnel (El-Rayes et al. 2014), four feasible alternatives for the access and egress method variable were identified in the present model. These four alternative methods for controlling the access and egress points in work zones require the use of flagger, spotter, access ramp, or no access and egress control. Each of these alternative methods was reported to have a different impact on work zone safety and mobility (El-Rayes 2014). For example, the use of flagger to control access and egress points was reported in the aforementioned survey and field studies to (a) protect workers from traffic hazards by reducing or stopping the traffic for trucks accessing or exiting the work zone; and (b) often cause drastic slowdown of the traffic and longer queue lengths. The impacts of these alternative methods on delays are quantified by the anticipated stop times of traffic in the live lanes to allow a safe entry and exit of construction vehicles to and from the work zone for each method based on the aforementioned field studies. To ensure the flexibility of the developed model, it is formulated to allow planners to list available access and egress methods on their projects and specify their impact on work zone safety and mobility.

7.3. OPTIMIZATION FUNCTIONS PHASE

The two main objective functions of this optimization model are to: (1) minimize work zone risks and hazards, and (2) minimize work zone-related traffic delays. These two main objectives are designed to integrate the impact of all the aforementioned decision variables and the following sections describe their formulation.

7.3.1. Minimize Probability of Work Zone Crashes

The probability of work zone crashes is represented in this model by a crash index *CI* that quantifies the collective impact of the aforementioned work zone layout decision variables, as shown in Equation (7.1). This crash index *CI* can then be used to estimate the total number of crashes $N_{Crashes}$ in the work zone area based on the total length of the project L_T and the average number of work zone crashes per mile $R_{Crashes}$, as shown in Equation (7.2) (Bauer et al. 2004, FHWA 2015).

$$\text{Minimize } CI = (\beta_{SPEED} \times \beta_{CT} \times \beta_{SH} \times \beta_{LC} \times \beta_{D} \times \beta_{TTC} \times \beta_{AE}) \times \beta_{WL} \times \beta_{L} \qquad (7.1)$$

$$N_{Crashes} = CI \times L_T \times R_{Crashes} \qquad (7.2)$$

Where,

β_{SPEED} = probability of crash occurrence due to posted speed limit; β_{CT} = probability of crash occurrence due to construction start time; β_{SH} = probability of crashes occurrence due to available shoulder width; β_{TTC} = cumulative probability of crash occurrence due to chosen TTC measures in work zones; β_{LC} = probability of crash occurrence due to lateral clearance; β_{D} = probability of crash occurrence due to work zone duration; β_{AE} = probability of crash occurrence due to access and egress method; β_{WL} = probability of crash occurrence due to the width of the live lane; and β_{L} = probability of crash occurrence due to the effective length of the work zone.

The model utilizes a methodology for calculating the combined impact of these probability of crashes that is similar to the ones used by the FHWA and Highway Safety

Manual (HSM 2000) for calculating crash modification factors (CMF) (http://safety.fhwa.dot.gov/tools/crf/; HSM 2000). CMF is a multiplicative factor used to estimate the expected number of crashes after implementing a given countermeasure at a specific site (Gross and Yunk 2011, Gross et al. 2012). The value of these CMF factors represent the increase or decrease in probability of crashes due to the selected values of decision variables. The value of CMF is set to equal 1.0 if the value of the decision variable has neutral effect on the probability of crashes in the work zone. The factor is less than 1.0 if the value of the decision variable can reduce the probability of crashes and greater than 1.0 if the selected value of the variable can increase the probability of crashes. For example, the risk factor is 1.2 if the value of the decision variable will increase the probability of crashes by 20%.

The model enables planners to (a) specify the values of the probability of crash occurrence due to each decision variable β_i based on the specific conditions of the work zone; or (b) use the default values in Table 7.1 that were identified based on the findings of a national survey of DOT engineers and work zone personnel (El-Rayes et al. 2010). These default values of the probability of crash occurrence are based on the direct impact of the aforementioned seven decision variables: (1) posted speed limit β_{SPEED}; (2); time of construction β_T; (3) shoulder use β_{SH}; (4) temporary traffic control method β_{TTC}; (5) lateral clearance width β_{LC}, (6) length/duration of work zone β_D and (7) access and egress method, as shown in Table 7.1. It should be noted that the model calculates the probability of crashes for each single hour of the daily work zone duration to consider the impact of daytime and nighttime work on safety. The probability of crash occurrence due to construction time β_{CT} is the average of the hourly probability of crash occurrence β_{Ti} calculated for each working hour for the total daily duration of the work zone, D_d, as shown in Equations (7.3 and 7.4).

$$\beta_{CT} = \frac{\sum_{t}^{t+D_d} \beta_{T_i}}{D_d} \tag{7.3}$$

$$D_d = a_1 + (a_2 \times L_{SA}) \tag{7.4}$$

Table 7.1 Default Values of Probability of Crash Occurrence Factors

Work Zone Speed Limit	β_{SPEED}	**Lateral Clearance**	β_{LC}
55 k/h (35 *mph)*	*1.0*	3.33 meters (10 ft.)	*1.0*
72 k/h (45 *mph)*	*1.16*	0.67 meters (2 ft.)	*1.03*
88 k/h (55 *mph)*	*1.35*	1.35 meters (4 ft.)	*1.05*
105 k/h (65 *mph)*	*1.53*	2 meters (6 ft.)	*1.15*
112 k/h (70 *mph)*	*1.60*	2.67 meters (8 ft.)	*1.20*
Work Zone Duration	β_D	**Temporary Traffic Control,** *(TTC)*	β_{TTC}
1 Hour < D < 1 day	*1.0*	Automated Photo Enforcement	*0.83*
1 > D > 3 days	*1.13*	Flagger	*0.9*
D > 3 days	*1.20*	Portable Changeable Message Signs *(PCMS)*	*0.84*
Construction Working Hour	β_T	Truck Mounted Attenuators *(TMAs)*	*1.0*
10:00 am to 03:00 pm	*1.0*	Speed Displays	*0.98*
04:00 pm to 8:00 pm	*1.20*	Police	*0.56*
09:00 pm to 05:00 am	*1.25*	**Access and Egress Method**	β_{AE}
06:00 am to 09:00 am	*1.15*	AE = 1 (Using flagger)	*0.90*
Use of Shoulders	β_{SH}	AE = 2 (Using spotter)	*0.90*
Full Shoulders available	*1.0*	AE = 3 (Using access ramp)	*1.0*
Narrow Shoulders < 6 ft	*1.10*	AE = 4 (No control method)	*1.10*
Full shoulder used as traffic lane	*1.21*		

In addition to the seven direct impact factors in Table 7.1, the model considers two additional indirect impacts of the aforementioned decision variables on (a) total length of the work zone area, and (b) the width of the live lane. The first indirect impact of the aforementioned decision variables is quantified in this model by calculating the probability of crash occurrence due to total length of the work zone area β_L. This β_L factor considers the increased probability of crashes that are caused by the longer overall length of all the project work zones L_{TWZ} compared to the actual length of the project L_T, as shown in Figure 7.7 and Equation (7.5).

$$\beta_L = \frac{Total\ length\ of\ work\ zones, L_{TWZ}}{Length\ of\ \ the\ Project, L_T} \quad (7.5)$$

$$L_{TWZ} = N_{WZ} \times L_{WZ} \quad (7.6)$$

$$L_T = N_{WZ} \times L_{WS} \quad (7.7)$$

$$L_{WZ} = L_{WS} + L_{TB} \quad (7.8)$$

Where,

L_{TWZ} = overall length of all the project work zones;

L_{WZ} = total length of the work zone;

L_{WS}= value of work space length decision variable; and

L_{TB} = summation of all buffers and tapers lengths according to (MUTCD 2009).

The second indirect impact of the aforementioned decision variables is quantified by calculating the probability of crash occurrence due to the width of the live lane β_{WL}. β_{WL} is identified using four steps that are designed to (a) calculate the available width of the highway for traffic W_{LA} after considering the impact of lane closures and shoulder use, as shown in Equation (7.9); (b) determine the number of open lanes in the work zone area $N_{Openlanes}$ based on the available width for traffic W_{LA} and the minimum lane width W_{Min}, as shown in Equations (7.10 and 7.11); (c) compute the effective width of work zone lane W_L based on the available width of the highway W_{LA} and the number of open lanes $N_{Openlanes}$, as shown in Equation (7.12); and (d) identify the probability of crash occurrence due to the effective width of work zone traffic lane β_{WL}, as shown in Table 7.2.

$$W_{LA} = (N_{Lanes} - N_{closedlanes}) \times W_{TYP} + SH - LC \quad (7.9)$$

$$\text{If } \frac{W_{LA}}{N_{Lanes} - N_{closedlanes} + 1} \geq W_{Min}; \text{ then } N_{Openlanes} = N_{Lanes} - N_{closedlanes} + 1 \quad (7.10)$$

$$\text{If } \frac{W_{LA}}{N_{Lanes} - N_{closedlanes} + 1} < Wmin; \text{ then } N_{Openlanes} = N_{Lanes} - N_{closedlanes} \quad (7.11)$$

$$\text{Effective width of work zone lane, } W_L = \frac{W_{LA}}{N_{Open\ lanes}} \quad (7.12)$$

Where,

W_{LA} = Available width of the highway for traffic

N_{lanes} = Number of original Highway lanes away from the work zone area

$N_{Openlanes}$ = Number of open lanes for traffic at the work zone area

$N_{Closedlanes}$ = Number of closed lanes for work zone

W_{Min} = Minimum value of work zone lane width specified by the planner.

Table 7.2 Default Values of Probability of Crash Occurrence for Different Lane Widths

Effective Width of Work Zone Traffic Lane, W_L	(β_{LW})
$W_L \geq$ 3.6 m (12 ft.)	1.0
W_L = 3.3 m (11 ft.)	1.08
W_L = 3.0 m (10 ft.)	1.21
W_L < 3.0 m (10 ft.)	1.29

7.3.2. Minimize Work Zone Traffic Delay

The work zone delay in the present model is calculated using the methodology previously described in section 6.3.1 of the previous chapter. This method calculates the moving, queue delay and total delay for the total duration of the project. The moving delay is calculated based on the difference between work zone actual speed and the highway speed, while the moving delay is calculated to account for the difference between the work zone traffic capacity and the actual hourly traffic demand (Benekohal et al 2010, HCM 2000).

7.4. CONSTRAINTS IDENTIFICATION PHASE

The model is designed to consider all relevant practical constraints that can be specified by the user to define the lower and upper boundaries of work zone length, speed limit, lane width, shoulder use, and lateral clearance, as shown in Table 7.3.

Table 7.3. Model Constraints

Constraints	**Minimum Value**	**Maximum Value**
Work Space Segment Length (L_{WS})	(User specified)	$\mathrm{L_{WZ}(max)} = \frac{24 - a_1}{a_2}$
Lane width (W_L)	(User specified)	3.6 m (12 ft.)
Shoulder Use (SH)	0	(User specified)
Lateral Clearance (LC)	(User specified)	(User specified)

7.5. IMPLEMENTATION PHASE

The main purpose of this phase is to implement the formulated model to enable the optimization of work zone layout parameters and the identification of optimal tradeoffs between minimizing traffic delays and probability of crash occurrence. Non-Dominated Sorting Genetic Algorithm (NSGA2) is used to perform the optimization computation of the multi-objective optimization problem. NSGA2 provides the capability of generating optimal tradeoffs among all objectives in a single run and utilizing an elitist strategy that prevents the loss of optimal solutions once they are found (Deb et al. 2000). NSGA2 adopts the survival of the fittest approach in addition to the concept of Pareto optimality in order to converge to a set of non-dominated optimal solutions that represent various tradeoffs among the optimization objectives (Zitzler and Thiele 1999; Deb et al. 2000).

The present model is implemented in four main steps: (1) an initialization step that creates an initial population of randomly generated layout parameters solutions for the problem; (2) a fitness evaluation step that calculates the values of crash index and traffic delay for each of the generated solutions; (3) a ranking step that ranks the generated solutions based on non-domination criteria; and (4) a generation evolution step that creates new populations of solutions using the genetic algorithm operations of selection, crossover, and mutation (El-Rayes and Kandil 2005). This process is repeated until a defined number of generations is completed.

7.6. APPLICATION EXAMPLE

An application example of a highway work zone was analyzed to illustrate the use of the model and demonstrate its capabilities in generating optimal trade-offs between highway work zone crash index and traffic delay. The example focuses on optimizing the layout for maintenance work zone on an existing highway that has a length of 17 km (10-mile). The existing highway has a speed limit of 110 km/h (70 mph) with two lanes and two standard shoulders with a width of 3.6 meter (12 feet) each. The work zone requires full closure of one lane and one shoulder at a time while keeping the other lane and shoulder open for traffic. The hourly traffic flow data for this application example are shown in Figure 7.8, and its work zone input data and constraints are listed in

Table 7.4.

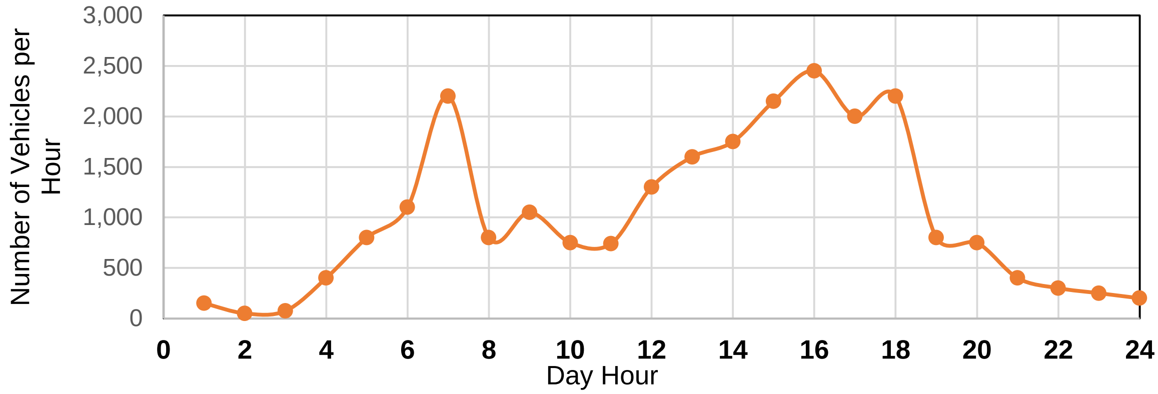


Figure 7.8. Hourly Traffic Flow Data

Table 7.4. User-specified Work Zone Input Data

Input Data	Description	Value
SL_{HW}	Posted speed limit at the highway	110 km/h (70 mph)
a_1	Fixed setup time for one work zone segment	2 hour
a_2	Average construction/maintenance time	3.75 hour/km (6 hour/mile)
L_{WS} (min)	Minimum work space length	0.8 km (0.5 mph)
L_T	Total Length of the project	16.1 km (10 miles)
SL_{MIN} / SL_{Max}	Minimum / Maximum Speed Limit	75 km/h / 110 km/h (50 mph) /(70 mph)
LC_{MIN} / LC_{Max}	Minimum/Maximum Lateral Clearance	0.67 m (2ft.) / 1.35 m (6ft.)
N_{AE}	Number of trucks entering work zone	3 per hour

The developed model is used to optimize the work zone layout parameters and traffic control measures for this application example in order to generate and analyze optimal tradeoffs between the two important objectives of minimizing the probability of crashes and minimizing traffic delays in the work zone area. The model is used to search for and identify Pareto-optimal (i.e., non-dominated) solutions where each provides a unique and optimal tradeoff between the two objectives, as shown in Figure 7.9. Each of these optimal tradeoffs can be achieved by implementing an optimal configuration of the work zone layout that specifies an optimal posted speed limit, construction start time, lateral clearance, work zone segment length, temporary traffic control device, and access and aggress method.

The generated tradeoffs for this example cover a wide spectrum that ranges from solution 1 that provides the least traffic delay (387 Veh/ Hr) to solution 2 that provides the least the probability of crashes (crash index = 0.71), as shown in Figure 7.9. On one end of this spectrum, optimal solution 1 was able to achieve the least traffic delay (387 Veh/ Hr) by selecting (1) the highest speed limit of 110 k/h (70 mph) to maximize mobility; (2) the shortest work space segment of 0.8 km (0.5 mile) because longer work space segments increase traffic delays and queue lengths in the work zone area; (3) a construction start time at 1:00 am to schedule construction work during low-traffic nighttime hours; (4) the maximum later clearance of 6 feet to increase the separation distance between traffic and the work area without reducing the width of open lanes to improve traffic mobility; (5) the maximum shoulder width of 12 feet to allow the use of shoulder as an additional traffic lane; and (6) the use of TMA as the only TTC measure in the work zone because of the impact of other TTC measures on reducing traffic speeds.

On the other end of the generated tradeoff spectrum in in Figure 7.9, optimal solution 2 was able to provide the least crash index (0.71) by selecting (1) the least speed limit from the specified feasible range in this example of 82 k/h (50 mph) to maximize work zone safety; (2) the longest work space segment of 3.27 km (2.0 miles) to reduce the overall length of all the project work zones L_{TWZ} (see Figure 7.7) to minimize the interrupted length of the highway by the work zone and minimize its probability of crashes; (3) a construction start time at 6:00 am to avoid the additional safety hazards encountered during nighttime construction; (4) the maximum lateral clearance of 6 feet to increase the separation distance between traffic and the work area to improve safety; (5) the use of 6 feet of shoulder for traffic to provide the aforementioned lateral clearance of 6 feet without reducing the width of open traffic lanes while maintaining the remainder 6 feet of shoulder to maximize safety; and (6) the use of auto photo enforcement, flagger, PCMS, TMA, speed displays, police patrol to maximize safety.

Optimal trade-offs generated by the model (see Figure 7.9) enable decision makers to select an optimal work zone layout that best fits the specific requirements of the project. Planners can analyze these generated trade-offs to identify (1) the minimum risk that can be achieved for a specified maximum allowed traffic delay; or (2) the minimum traffic delay that can be achieved for a defined maximum allowed probability of crashes. For example, solution A represents the optimum work zone layout that provides the minimum traffic delay (1,161 Veh/Hr) for a crash index under the limit of 2.0, as shown in Figure 7.10. On the other hand, solution B represents the optimum work zone layout that provides the minimum crash index (0.92) for a traffic delay below 50,000 Veh/Hr.

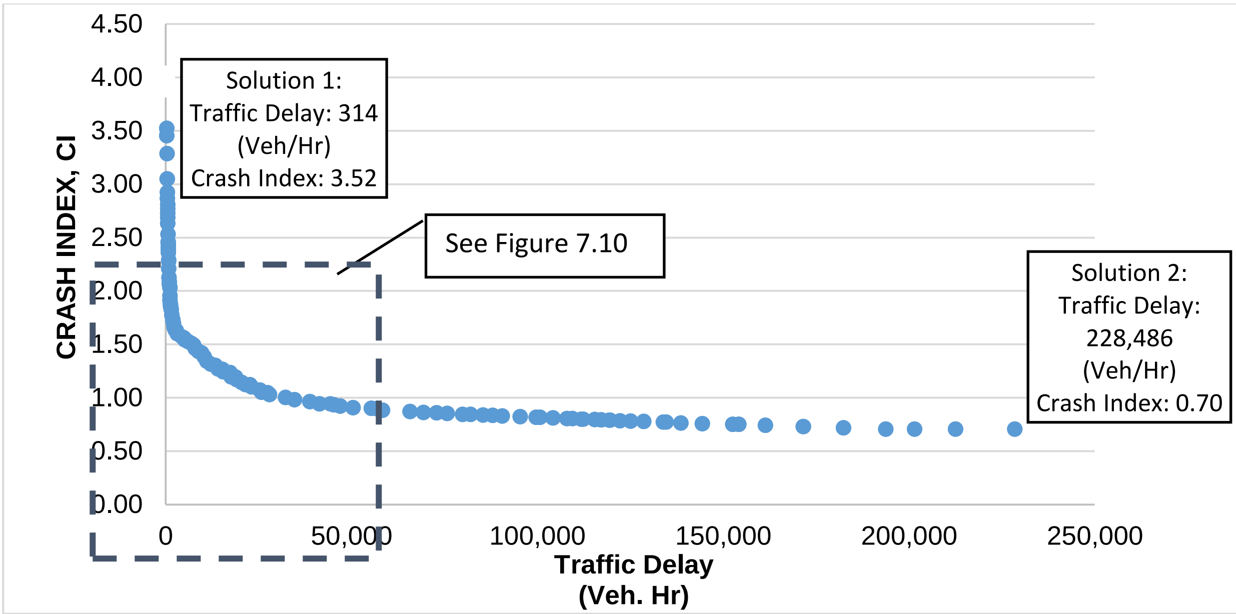


Figure 7.9. Optimal Tradeoffs between Work Zone Traffic Delay and Crash Index

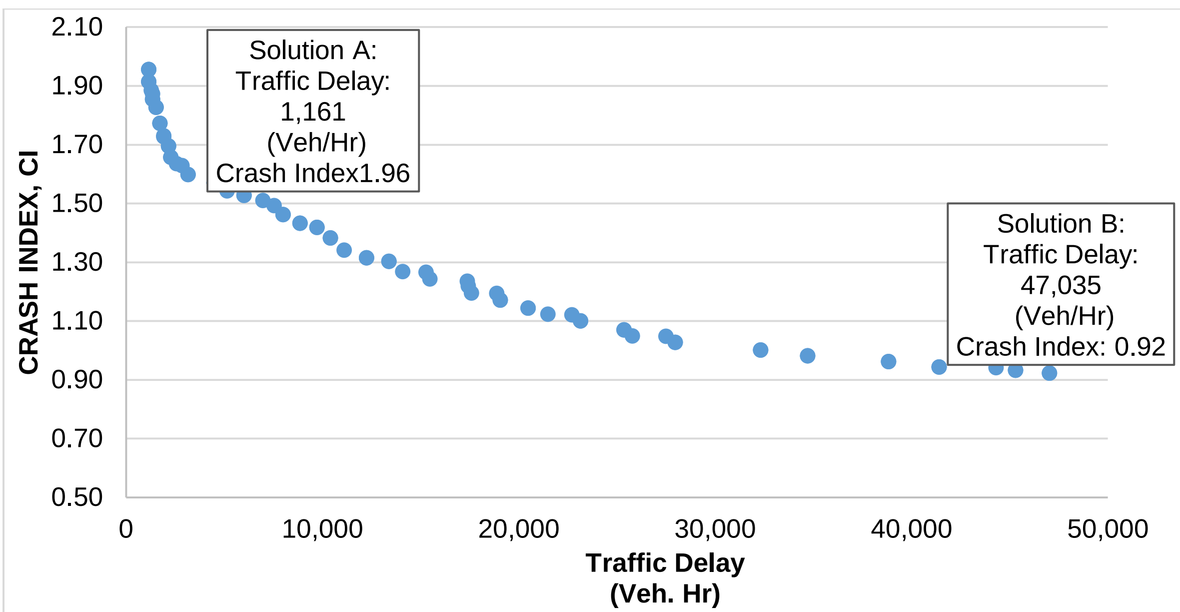


Figure 7.10. Subset of Generated Optimal Tradeoffs between Work Zone Traffic Delay and Crash Index

Table 7.5. Optimal Work Zone Layout Decisions for Sample Solutions

Decision Variable	SOLUTION 1	SOLUTION A	SOLUTION B	SOLUTION 2
Speed (mph)	70	70	50	50
LS (km)	0.8 km (0.5 miles)	1.0 km (0.62 miles)	2.1 km (1.33 miles)	3.27 km (2.0 miles)
Construction Start Time (t)	1:00 (AM)	1:00 (AM)	(7:00 PM)	6:00 (AM)
Access and Egress	No Control	Flagger	Flagger	Flagger
Lateral Clearance	2 m (6 ft.)	2 m (6 ft.)	2 m (6 ft.)	2 m (6 ft.)
Shoulder Use	3.6 m (12 ft.)	3.6 m (12 ft.)	2 m (6 ft.)	2 m (6 ft.)
Auto Photo Enforcement	-	X	X	X
Flagger	-	X	X	X
PCMS	-	X	X	X
TMA	X	X	X	X
Speed Displays	-	-	X	X
Police Patrol	-	-	X	X
Use Shoulder as Traffic Lane	X	X	-	-
Traffic Delay (Veh.Hr)	**314**	**1,161**	**47,035**	**228,486**
Crash Index (CI)	**3.52**	**1.96**	**0.92**	**0.70**

7.7. CONCLUSIONS

A novel multi-objective optimization model was developed to generate optimal trade-offs between the two conflicting work zone layout objectives of minimizing the probability of crash occurrence and minimizing traffic delay. The model was designed to optimize work zone layout parameters including work zone speed limit, construction start time, shoulder use, lateral clearance, work zone segment length, temporary traffic control measures, and work zone access and egress method. The performance of the developed model was evaluated using an application example of highway resurfacing project. The results of this analysis illustrated the unique capabilities of the model in generating a wide spectrum of Pareto-optimal solutions, where each identifies an optimal work zone layout that provides a unique and optimal trade-off between the two optimization objectives of minimizing probability of crash occurrence and traffic delay. At one end of the generated spectrum, the minimum traffic delay solution was achieved by using the maximum specified posted work zone speed limit, starting construction work at night, providing 2 meters (6 ft.) of lateral clearance, and 3.6 meters (12 ft.) shoulder use which allows the use of the shoulder as an extra traffic lane, using 1.8 meter (6 feet) of the shoulder for temporary traffic use, minimizing the work zone segment length using only TMA as TTC for the work zone and using flagger to control access and egress. At the other end of the spectrum, the minimum crash index solution was achieved by using minimum specified work zone speed limit, performing work during daytime hours, performing work during daytime, using 2 meters (6 feet) lateral clearance, using 2 meters (6 feet) of shoulder that maintain the standard maximum lane width, using longer work space segment, using auto photo enforcement, flagger, PCMS, TMA, speed displays, police patrol to maximize safety as TTC measures and use flagger to control access and egress points. In addition to these two extreme solutions, the model was able to generate a wide range of optimal tradeoffs that can be used by decision makers to select an optimal tradeoff that satisfies the specific priorities and agency constraints of the project. These new and novel capabilities are expected to improve existing practices for designing highway work zone layouts, can lead to improved traffic mobility, and reduced work zone crashes. The primary contributions of this research to the body of knowledge include the development of (1) an original and comprehensive set of metrics for measuring and quantifying the impact of the important work zone layout parameters of shoulder use, lateral clearance, work space segment length, and work zone access and egress method on traffic delays and probability of crashes; and (2) a novel multi-objective optimization methodology for generating and analyzing optimal tradeoffs between the two critical work zone layout objectives of minimizing traffic delays and probability of work zone crashes.

CHAPTER 8
CONCLUSIUONS

8.1. SUMMARY

This research study focused on investigating and optimizing the planning of highway work zones in order to support state DOTs in their ongoing efforts to maximize work zone safety, mobility, and cost effectiveness. The scope of this study focused on: (1) evaluating the effectiveness of current TTC practices and work zone layout parameters in improving safety and mobility; (2) analyzing work zone crash data to study the frequency and severity of traffic-related work zone crashes, and investigate the probable causes and contributing factors of these crashes; (3) gathering and analyzing feedback from DOT resident engineers and highway contractors on the effectiveness and benefits of TTC measures and other layout parameters such as flaggers and spotters; (4) developing a novel multi-objective optimization that is capable of generating and analyzing optimal tradeoffs between minimizing traffic delays and construction cost; and (5) creating an innovative multi-objective optimization model that provides a wide range of optimal tradeoffs between minimizing traffic delays and probability of crashes.

First, field studies were conducted to evaluate the layout design, TTC measures and safety devices that were used in seven highway work zones. During these field studies, data were gathered on (1) type of construction operations performed in each work zone, (2) layout of the work zone and its TTC measures, (3) impact and effectiveness of using flaggers if any on safety and mobility, and (4) impact of access and egress methods on safety and mobility.

Second, a comprehensive work zone crash analysis was conducted to analyze crashes in Illinois during a fourteen-year period, from 1996 to 2009. The objectives of this analysis were (1) to study the frequency and severity of work zone crashes on Illinois expressways and freeways, and (2) to investigate the probable causes and factors contributing to work zone crashes.

Third, two surveys were conducted to gather and analyze feedback from engineers and construction personnel in IDOT and other state DOTs on the effectiveness of TTC measures and safety devices such as flaggers and spotters in directing work zone traffic on freeways and expressways with a posted speed limit greater than 40 mph. The surveys were designed to gather and analyze data on (a) need, benefits, and risks of using flaggers in and around work zones, (b) spotter functions, benefits, and risks, (c) effectiveness, need, and risks of using spotters instead of flaggers in work zones, and (d) effectiveness of using TTC devices and various safety measures in improving the safety of work zone access and egress points.

Fourth, a novel multi-objective optimization model was developed to generate optimal tradeoffs between minimizing traffic delays and construction costs by identifying optimal solutions for all related work zone layout parameters such as segment length, starting time, shoulder use, lateral clearance, and work zone access. The performance of the developed model was analyzed using an application example. The results of this performance analysis illustrated that the model is capable of generating a wide range of optimal work zone layouts where each provides an optimal tradeoff between the two objectives of the model.

Fifth, a new and innovative multi-objective optimization model was developed to generate optimal tradeoffs between minimizing traffic delays and minimizing the probability of work zone crashes. The model provides the capability of searching for and identifying a set of Pareto optimal solutions for work zone layouts that specifies an optimal solution for work zone speed limit, construction start time, shoulder use, lateral clearance, work zone segment length, TTC measures, and work zone access and egress method. The optimization model includes an innovative crash index that was developed to quantify work zone risks and traffic hazards due to work zone layout and TTC measures.

8.2. RESEARCH CONTRIBUTIONS

The main research contributions of this study can be summarized as follows:

1) Creating new knowledge on the impact of work zone layout parameters such as nighttime construction, speed limit, and TTC measures on the frequency and severity of work zone crashes based on a comprehensive analysis of 28,850 records of highway work zone crashes.

2) Generating new knowledge on the effectiveness of using flaggers, spotters and other TTC measures in work zones with a speed limit greater than 40 mph based on a comprehensive survey of state DOTs.

3) Forming new metrics to quantify the impact of work zone access and egress methods on traffic delays, construction cost, and probability of crashes.

4) Producing a novel crash index to quantify the collective impact of work zone layout parameters on the probability of crashes in highway work zones.

5) Developing an innovative multi-objective optimization model for work zone layout planning that is capable of generating optimal tradeoffs between minimizing traffic delays and minimizing construction cost.

6) Creating a novel work zone layout optimization model that that can be used by state DOTs to generate and analyze optimal tradeoffs between minimizing traffic delays and minimizing the probability of crashes in the work zone area.

8.3. RESEARCH IMPACT

The application of the aforementioned novel metrics and models for optimizing the planning of highway work zones is expected to provide broad and profound impacts on work zone safety, mobility, and cost effectiveness. These models can be used by state DOTs to identify and implement optimal work zone layouts that are capable of (a) minimizing the probability of crashes in highway work zones; (b) maximizing the safety of work zone workers and the traveling public; (c) minimizing work zone traffic congestions and delays; (d) minimizing drivers delays and their related non-productive time and frustrations; (e) minimizing the emissions of idle vehicles in work zone areas and reducing their negative environmental impacts; (f) minimizing work zone cost to ensure the cost effectiveness of public expenditures on highway construction projects. Furthermore, the application of the aforementioned optimization models enables state DOTs to accomplish their stated policies for work zone safety and mobility such as IDOT policy that included the goals of (1) achieving zero worker fatalities in work zones, (2) reducing work zone crashes and number of motorists' fatalities in work zone related crashes, and (3) minimizing delay due to work zones to be less than 5 minutes per mile (IDOT 2007).

8.4. FUTURE RESEARCH

Although the present study was able to fully accomplish its research objectives, a number of additional research areas have been identified to expand and build on the completed research work in this study. These future research areas include: (1) investigating the impact of various work zone access and egress methods on safety and mobility; (2) analyzing and minimizing the impact of work zone layout on traffic emissions; (3) minimizing the probability of fatal and injury crashes; and (4) developing a comprehensive work zone layout optimization model to identify optimal tradeoffs among probability of crashes, traffic delays, traffic emissions, and construction cost.

8.4.1. Assessment of work zone access and egress points

The survey respondents in chapter 5 recommended further investigation of the effectiveness of various work zone access and egress methods in improving safety and mobility. The access and egress methods that were recommended for further investigation include (a) incorporate access/egress into internal traffic control plan, (b) build temporary ramp to provide median access from street overpass, (c) improve lighting condition and visibility of access and egress points during nighttime work zone, and (d) equip the rear of construction vehicles entering the work zone with a warning sign. Accordingly, this proposed investigation of access and egress methods can be accomplished using the following research tasks that focus on: (1) conducting case studies to analyze the performance of a set of identified work zones that utilize various measures and/or layouts for controlling the entrance and exit of trucks; (2) collecting field data from the identified case studies using fixed cameras and speed monitoring devices to continuously monitor and record traffic speed, safety, and mobility conditions as well as specific traffic operations at the work zone access and egress points; (3) analyzing the collected data to evaluate the effectiveness of various measures and/or layouts for controlling the entrance and exit of trucks and identify their impact on work zone safety and mobility; and (4) providing recommendations to improve safety and mobility at work zone access and egress points.

8.4.2. Minimizing the impact of work zone layout on traffic emissions

The Environmental Protection Agency (EPA) recently reported that approximately 23% of national greenhouse gas emissions are attributed to roadway vehicles (EPA 2013). This highlights the need to expand the developed optimization models in this study to quantify and minimize the impact of work zone layout on traffic emissions. To enable this, the developed model needs to be expanded to account for dynamic traffic delay that considers propagation of queues that are caused by waves of stop-and-go traffic.

8.4.3. Minimizing the probability of fatal and injury crashes

The developed model for optimizing work zone layout in chapter 6 provides the capability of minimizing the two important objectives of minimizing traffic delays and minimizing the overall probability of crashes. The second objective of minimizing the overall probability of crashes can be expanded in future research to enable minimizing the impact of work zone layout on the probability of fatal crashes and the probability of injury crashes. Accordingly, the proposed multi-objective optimization can be expanded to quantify and generate optimal tradeoffs among the three optimization objectives of minimizing traffic delays, minimizing probability of fatal crashes, and minimizing probability of injury crashes in highway work zones. This proposed expansion of the model can enable decision makers to distinguish between the impacts of work zone layout parameters on the probability of fatal and injury crashes.

8.4.4. Comprehensive multi-objective optimization model for work zones

The two developed optimization models in this study can be combined with the aforementioned future research areas to create an expanded and comprehensive work zone layout optimization model. This comprehensive multi-objective optimization model will provide the capability of generating optimal tradeoffs among the critical work zone layout objectives of minimizing traffic delays, minimizing construction cost, minimizing traffic emissions, minimizing probability of fatal crashes, and minimizing probability of injury crashes. This will enable planners in state DOTs to generate and analyze a wide range of optimal tradeoffs among these work zone layout objectives in order to identify an optimal work solution that strikes an optimal balance among them.

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APPENDIX A
WORK ZONE CRASH DATA COLLECTION AND ANALYSIS

A.1 ANALYSIS OF WORK ZONE CRASH DATA

Work zone crashes are defined as crashes that occur in the terrain of a work zone whether it is a construction, maintenance, or utility work zone (MUTCD 2009). This section summarizes the frequency and severity as well as other characteristics of injury and fatal work zone crashes in Illinois.

A.2.1 Data Fusion

The crash data in the collected datasets were organized and grouped in five main steps.

1. Filter the data to only highways.
2. Filter the data to only work zones related crashes.
3. Exclude PDO crashes.
4. Gather the filtered data for each year in one large file.
5. Categorize some variables to match different description for each year.

The first step is extracting crashes on highway from all the available NHTSA data records for each year. The class of roads were identified as a subset of entire crash data set using the variable “FD_CLASS” in the crash file that Indicates the federal classification of the road where the crash occurred and has 14 possible values for the data from year (1994 to 2003) as shown in Table A.3 and 11 possible values from year (2004 to present) as shown in Table A.4. The values 01, 02, 11, and 12 for the years (1996 to 2003) represents Interstate (not on National Highway System), Freeway/expressway (not on National Highway System), Interstate (on National Highway System), and freeway/expressway (on National Highway System) respectively as same as the values 10 and 20 represents Interstate, and freeway and expressway respectively for the years (2004 to present).

Table A.1. Federal Classification of Highways (1994-2003)

Value (2004-present)	Meaning
0	Not available (when a code was not entered, in which case it defaulted to zero)
10	Interstate
20	Freeway and expressway
30	Other principal arterial
40	Minor arterial (non-urban)
50	Major collector (non-urban)
55	Minor collector (non-urban)
60	Local road or street (non-urban)
70	Minor arterial (urban)
80	Collector (urban)
90	Local road or street (urban)

Table A.2. Federal Classification of Highways (2004 – present)

(FD_CLASS)	Federal Classification of Highways Indicates the federal classification of the road where the crash occurred
Value (1994-2003)	**Meaning**
01	Interstate (not on National Highway System)
02	Freeway/expressway (not on National Highway System)
03	Major principal arterial (not on National Highway System)
04	Minor arterial (not on National Highway System)
05	Major collector (not on National Highway System)
06	Minor collector (not on National Highway System)
07	Local road (not on National Highway System)
11	Interstate (on National Highway System)
12	Freeway/expressway (on National Highway System)
13	Major principal arterial (on National Highway System)
14	Minor arterial (on National Highway System)
15	Major collector (on National Highway System)
16	Minor collector (on National Highway System)
17	Local road (on National Highway System)

The second step was extracting the work zone crashes from all filtered data. These work zone crashes were identified as a subset of the entire crash data set using the variable "RD_CON1" in the crash file that represents roadway condition and has 12 possible values, as shown in C.4. Values of 2, 3, 4, and 5 for this variable represent construction zone, maintenance zone, utility work zone, and work zone unknown, respectively. All crashes that had these values were extracted and listed under a new variable named "Road Condition" and were combined in a single spreadsheet. An advanced statistics program was used to import the collected data to be ready for statistical analysis.

Table A.3. NHTSA Road Condition Variable (RD_CON1)

Variable	Possible Values	Road Condition (RD_CON1)
Indicates a deficiency in the road where the crash occurred. In 2004, leading zeroes were dropped from this variable.	0	Not stated
	1	No defects
	2	Construction zone
	3	Maintenance zone
	4	Utility work zone
	5	Work zone-unknown
	6	shoulders
	7	Ruts/holes
	8	Worn surface
	9	Debris on roadway
	10	Other
	99	unknown

The third step involved extracting work zone injury and fatal crash records after excluding property damage only (PDO) work zone crashes for each year. Identifying injury and fatal crashes was performed using the variable "SEVERITY" in the crash file. The data files from 1996 to 2003 used the numerical values of 1 and 2 to represent fatal and injury crashes, while the data files from 2004 to 2009 used the alphabetical values of F and I to represent fatal and injury crashes, respectively as shown in A.4.

Table A.4. NHTSA Accident Severity Variable

Variable	Possible Values	Description
Accident Severity: Indicates the most severe injury sustained by any occupant or non-occupant involved in the crash.	1,F	Fatal
	2,I	Injury
	3,P	Property Damage Only (PDO)

The fourth step involved joining the crash, vehicle, and person files using the "CASE Number" and collecting all the filtered data for all the analysis years in one large spreadsheet/SAS data file. A sample of the spreadsheet that includes the first dataset of fatal work zone crashes is presented in Table A.21. This spreadsheet is designed to include all the available data in the data files obtained from the National Highway Traffic Safety Administration (NHTSA).

The fifth step was to categorize some variables for the purpose of the analysis. The cause variable was categorized into six groups and the hour of the accidents categorized into four times as described in the next section.

A.2.2 Categories of Crash Variables

For each of the listed fifteen variables in A.6, a comprehensive analysis was conducted to investigate and compare its individual impact on the frequency of: (a) fatal work zone crashes; and (b) all injury work zone crashes involving one or more vehicles. These fifteen variables were grouped into six main categories: (1) control variables; (2) road data; (3) time data; (4) crash severity data; (5) environmental conditions; and (6) causes of crash. The following sections provide list and describe the variables included in each of these six categories, as shown in A.6.

I. Control Variables

This category has two variables that represent the identity of the crash: (1) year of the accident; and (2) case number that lists the police case number. These two variables were used to identify each crash and to match it with police reports, if needed.

II. Road Data

This category includes the basic road characteristics of each work zone injury and fatal crash and is represented by six variables: (1) federal classification of highway; (2) road condition; (3) road surface condition; (4) route prefix; (5) traffic control; and (6) traffic control functionality. Road data variables are presented in Table A.9.

III. Time Data

This category includes two variables that represent: (a) the time of the crash; and (b) the day of the week. Similar to previous traffic-related crash studies, the time of the crash has been divided into four periods: (1) 6:01 – 10:00 representing the peak morning hours; (2) 10:01 – 16:00 representing the daytime non-peak hours; (3) 16:01 – 20:00 representing the afternoon/evening peak hours; and (4) 20:01 – 6:00 representing the nighttime hours. Time data variables and their data are listed in A.7.

IV. Severity Data

This category includes the main characteristics of injury and fatal crashes represented by five variables: (1) total number of fatalities; (2) total number of injuries; (3) number of vehicles involved; (4) Accident Severity; and (4) type of collision. Crash data variables are listed in A.6.

V. Environmental Condition

This category represents two variables: (1) light condition; and (2) weather condition. These two variables are presented in A.19 and Table A.20.

VI. Contributing Causes Data

This category is represented by two variables: (1) contributing cause1; and (2) contributing cause 2. Both variables indicate any action the driver did to contribute to the crash according to police reports. The driver contributing causes include 35 categories (for the data sets from 1996 to 2001) representing all possible contributing causes of a crash such as: failed to yield, disregarded control devices, too fast for conditions, wrong way/side, and followed too closely. (From the year 2002 to present) the contributing cause expanded to be 38 causes including more distraction causes like Distraction-from outside vehicle, Distraction-from inside vehicle, and Distraction-operating a wireless phone. These 31/38 different contributing causes were grouped and divided into 6 major contributing causes: (1) improper driving; (2) distraction; (3) work zone environment; (4) disregarding traffic control; (5) speed; and (6) unknown. Contributing cause variables are listed in A.16a and A.16b.

Table A.5. Summary of Analysis Variables

Variable Name	Meaning	Observations

Control Variables	Year	Year of the accident	Actual Number
	CASENO	*Case No.*	Actual Number
Road Data	RTE_PREF	*Route Prefix*	See Table A.13.
	RD_CON1	*Road Condition*	See Table A.11.
	TRA_CON1	*Traffic Control*	See Table A.14.
	TRA_FUN1	*Traffic Function*	See Table A.15.
	RD_CLASS	*Road Class*	See Table A.9.
	Road Surface	*Road Surface*	See Table A.12.
Time Data	Time	*Time of the accident (Hour)*	See Table A.6.
	WEEKDAY	*Day of the week*	See Table A.7.
Crash Severity Data	Collision	*Type of collision*	See Table A.8.
	SEVERITY	*Accident Severity*	See Table A.4.
	NUM_VEH	*Number of Vehicle involved in the accident*	Using Actual Number
	NUM_FAT	*Number of fatalities in the accident*	Using Actual Number
	NUM_INJ	*Number of injuries the accident*	Using Actual Number
Environmental Condition	LIGHT	*Lightening Condition*	See Table A.18.
	WEATHER	*Weather Type*	See Table A.19
Causes	Cause 1	*1st Cause of the Accident*	See Table A.16a &A.17b.
	Cause 2	*2nd Cause of Accident*	See Table A.16a &A.17b.

Table A.6. Observations for Time Data (Time of the Accident)/ (AccHour)

Variable	Number	Description
Time of the accident: Indicates the time period in which an accident occurred.	1	06:01:10:00 (Morning peak hours)
	2	10:01:16:00 (Daytime non-peak hours)
	3	16:01:20:00 (Afternoon peak hours)
	4	20:01:06:00 (Nighttime hours)

Table A.7. Observations for Time Data (Day of the Week)

Variable	Number	Description
Day of week: Indicates the day of the week on which the crash occurred.	1	Monday
	2	Tuesday
	3	Wednesday
	4	Thursday
	5	Friday
	6	Saturday
	7	Sunday

Table A.8. Observations for Crash Data (Type of Collision)

Variable	Number	Description
Type of Collision: Indicates the type of crash.	00, 99	Not stated, Unknown
	1	Pedestrian
	2	Pedalcyclists
	3	Train
	4	Animal
	5	Overturned
	6	Fixed object
	7	Other object
	8	Other non-collision
	9	Parked motor vehicle
	10	Turning
	11	Rear-end
	12	Sideswipe—same direction
	13	Sideswipe—opposite direction
	14	Head-on
	15	Angle

Table A.9. Observations for Road Data (Class of Traffic way)

Variable	Number	Description
Class of traffic way : Indicates the classification of the road where the crash occurred.	0	Rural—unmarked state highway
	1	Rural—controlled access highway
	2	Rural—other marked state highway
	3	Rural—county/local road
	4	Rural—toll road
	5	Urban—controlled access highway
	6	Urban—other marked state highway
	7	Urban—unmarked state highway
	8	Urban—city street
	9	Urban—toll road

Table A.10. Observations for Road Data (Federal Classification of Highway)

Variable	Number	Description
Federal Classification of Highway: Indicates the federal classification of the roadway where the crash occurred.	01,10	Interstate (not on National Highway System)
	02,20	Freeway/expressway (not on National Highway
	03,30	Major principal arterial (not on National Highway
	04,40	Minor arterial (not on National Highway System)
	05,50	Major collector (not on National Highway System)
	06,60	Minor collector (not on National Highway System)
	07	Local road (not on National Highway System)
	11	Interstate (on National Highway System)
	12	Freeway/expressway (on National Highway System)
	13	Major principal arterial (on National Highway
	14, 70	Minor arterial (on National Highway System)
	15	Major collector (on National Highway System)
	16	Minor collector (on National Highway System)
	17, 90	Local road (on National Highway System)

Table A.11. Observations for Road Data (Road Condition)/(Type Construction)

Variable	Number	Description
Road Condition: Indicates a deficiency in the road where the crash occurred.	0	Not stated
	1	No defects
	2	Construction zone
	3	Maintenance zone
	4	Utility work zone
	5	Work zone—unknown
	6	Shoulders
	7	Ruts/holes
	8	Worn surface
	9	Debris on roadway
	10	Other
	99	Unknown

Table A.12. Observations for Road Data (Road Surface)/(Road Surface Condition)

Variable	Number	Description
Road surface: Indicates the road surface condition at the scene of the crash.	0	Not stated
	1	Dry
	2	Wet
	3	Snow/slush
	4	Ice
	5	Sand/mud/dirt/etA.
	6	Other
	9	Unknown

Table A.13. Observations for Road Data (Route Prefix)

Variable	Number	Description
Route Prefix: Indicates the route where the crash occurred.	0	Not applicable
	1	U.S. route
	2	Interstate business loop
	3	U.S. business route
	4	Bypass (in 1996, also means U.S. one-way couple)
	5	Illinois route
	6	Illinois alternate route (in 1996 also means Illinois one-way couple)
	7	Illinois business route (in 1996 also means interstate business loop one way couple)
	8	Non-marked route
	9	Interstate

Table A.14. Observations for Road Data (Traffic Control)

Variable	Number	Description
Traffic Control: Indicates the type of traffic signals or restrictions at the scene of the crash.	0	Not stated
	1	No traffic control
	2	Stop sign or red flasher
	3	Traffic control signal
	4	Yield sign or yellow flasher
	5	Police officer or flagman
	6	Railroad crossing gate
	7	Other railroad crossing device
	8	School speed zone
	9	No passing zone
	10	Other type regulation sign
	11	Other warning sign
	12	Lane use control marking
	13,99	Other, Unknown

Table A.15. Observations for Road Data (Traffic Control Functionality)

Variable	Number	Description
Traffic Control Functioning: Indicates the type of traffic control functioning at the scene of the crash.	0	Not stated
	1	No traffic control
	2	Not functioning
	3	Functioning improperly
	4	Functioning properly
	5	Reflecting material worn
	6	Missing
	7	Other
	8	Unknown

Table A.16a. Observations for Contributing Causes (Cause 1 &2)

Variable	Observation	Description
Contributing cause: *Indicate the actions of the driver that contributed to the crash.*	0	Not stated
	1	Exceeded authorized speed limit
	2	Right-of-way
	3	Following too closely
	4	Overtaking/passing
	5	Wrong side/way
	6	Improper turn/no turn signal
	7	Right turn on red
	8	Under the influence of alcohol/drugs (used when arrest is effected)
	9	Operated vehicle in erratic, reckless, careless, negligent or aggressive manner
	10	Equipment—vehicle condition
	11	Weather
	12	Road engineering/surface/markings/defects
	13	Road construction
	14	Vision obscured (signs, tree limbs, buildings, etc.)
	15	Driving skills, knowledge, experience
	16	Driver distraction/inattention
	17	Physical condition of driver
	18	Unable to determine
	19	Had been drinking (used when arrest is not made)
	20	Improper lane usage
	21	Swerved due to animal, object, non-motorist
	22	Disregarded yield sign
	23	Disregarded stop sign
	24	Disregarded other traffic signs
	25	Disregarded traffic signals
	26	Disregarded road markings
	27	Exceeded safe speed for conditions
	28	Failure to reduce speed to avoid crash
	29	Passed stopped school bus
	30	Improper backing
	31	Electronic equipment, i.e. cellular phone, Observations for Contributing Causes (Cause 1 &2) added after 2004

Table A.16b. Observations for Contributing Causes (1 &2) added 2002–Present

Variable	Observation	Description
Contributing cause: Indicate the actions of the driver that contributed to the crash.	32	Evasive action due to animal, object, non- motorist
	40	Distraction—from outside vehicle
	41	Distraction—from inside vehicle
	42	Distraction—operating a wireless phone
	50	Operated vehicle in erratic, reckless, careless, negligent or aggressive manner
	51	Not applicable (2002–2003)
	99	Not applicable

Table A.17. Observations for Contributing Causes (Categorized Contributing Causes)

Categorized Contributing Causes	Number	Description (See Table 17-A & 17-B)
Improper Driving	1	2,3,4,5,6,7,8,9,10,15,16,17,19,29,30
Distraction	2	31
Work Zone Environment	3	11,12,13,14,20,21
Disregarded Traffic Control	4	22,23,24,25,26
Unknown	5	0,18
Speed	6	1,27,28

Table A.18. Observations for (Light Condition)

Variable	Number	Description
Light Condition: Indicates the general light conditions prevailing at the time of the crash.	0, 9	Not stated
	1	Daylight
	2	Dawn
	3	Dusk
	4	Darkness
	5	Darkness—road lighted

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Table A.19. Observations for (Weather)

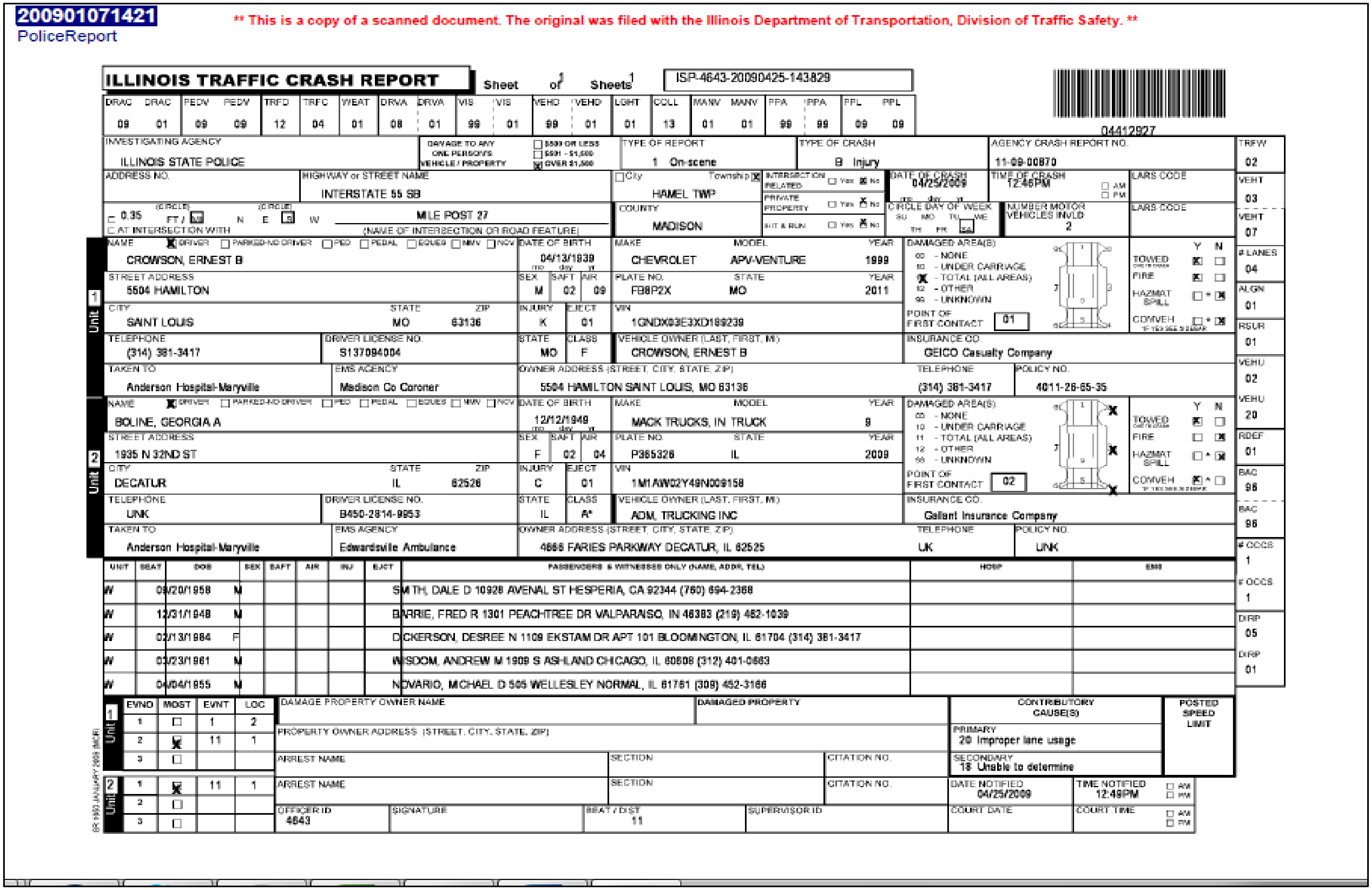
Variable	Number	Description
Weather: Indicates the weather conditions at the time of the crash.	0	Not stated, Unknown
	1	Clear
	2	Rain
	3	Snow
	4	Fog/smoke/haze
	5	Sleet/hail
	6	Severe crosswind
	7	Other

Table A.20. Sample NHTSA Dataset of Fatal Illinois Work Zone Crashes in 2005

Crash Number	Time Information			Accident Severity			Crash Information					
	Date of Accident	Time of Accident	Day of Week	Number of Fatalities	Number of Injuries	Total number Inj & Fat	County	Population Group	Enforcement Agency	Intersection Related	Number of Vehicles	Type of Collision
50000645	1172005	4	1	1	0	1	16	3	3	2	1	8
50056209	2272005	4	7	1	0	1	16	3	3	2	1	6
50075837	2272005	4	7	1	5	6	16	3	3	2	2	7
50150994	3022005	4	3	1	1	2	69	0	3	2	2	14
50199199	2282005	1	1	1	1	2	49	6	1	1	2	10
50301647	3072005	3	1	1	4	5	84	9	1	1	4	15
50349786	5072005	3	6	1	0	1	82	0	3	2	1	7
50442409	5182005	2	3	1	1	2	16	5	3	2	6	11
50514694	5182005	2	3	1	0	1	99	0	3	2	2	11
50780139	6242005	2	5	3	0	3	101	7	3	2	4	11
50808955	6122005	2	7	1	3	4	11	0	3	2	3	14
51648947	8052005	4	5	1	0	1	16	3	3	2	1	1
51653186	8292005	1	1	1	0	1	16	7	3	2	2	7
51685154	8312005	1	3	1	0	1	75	0	3	2	1	6
51731727	8312005	4	3	1	2	3	16	7	3	2	3	11
52009198	9052005	1	1	1	0	1	84	9	1	2	1	5
52154507	9272005	2	2	1	1	2	22	8	1	2	3	15
52155181	9262005	4	1	2	0	2	16	3	3	2	2	11
52376985	10142005	1	5	1	0	1	16	8	1	2	1	2
52807021	11162005	4	3	1	1	2	16	3	3	2	2	11
52807385	11192005	4	6	1	0	1	50	6	3	2	2	6

Table A.20 (continued). Sample NHTSA Dataset of Fatal Illinois Work Zone Crashes in 2005

Crash Number	Roadway Information							Contributing Causes		Climatic Information	
	Class of Trafficway	Federal Classification of Highways	Road Condition	Road Surface	Route Prefix	Traffic Control	Traffic Cont Functionality	Contributing Cause1	Contributing Cause2	Light Condition	Weather Condition
50000645	5	1	2	1	9	12	4	15	0	5	1
50056209	5	1	2	1	9	11	4	1	20	5	1
50075837	5	1	2	1	9	12	4	8	27	5	1
50150994	2	3	2	1	1	12	4	19	20	4	1
50199199	6	3	2	2	5	3	4	25	99	1	3
50301647	6	3	2	1	5	3	4	2	99	5	1
50349786	5	1	2	1	9	99	2	19	20	1	1
50442409	8	1	2	1	9	12	4	28	27	1	1
50514694	1	1	2	1	9	12	4	28	27	1	1
50780139	5	1	2	1	9	1	1	28	18	1	1
50808955	2	4	2	2	5	1	1	20	15	1	2
51648947	5	1	2	1	9	12	4	24	99	5	1
51653186	8	1	2	1		4	1	15	15	1	1
51685154	2	5	3	1	5	10	4	18	0	1	1
51731727	8	1	2	1	9	11	4	28	3	5	1
52009198	7	14	2	1	8	1	1	0	0	1	1
52154507	6	3	2	1	5	11	4	18	99	1	1
52155181	5	1	2	1	9	12	4	1	2	5	1
52376985	8	17	2	1		1	1	0	0	1	1
52807021	5	1	2	1	9	11	4	1	99	5	1
52807385	8	17	2	1		11	4	24	50	4	1



200901071421
PoliceReport

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ILLINOIS TRAFFIC CRASH REPORT Sheet 1 of 1 Sheets

ISP-4643-20090425-143829

04412927

DRAC	DRAC	PEDV	PEDV	TRFD	TRFC	WEAT	DRVA	DRVA	VIS	VIS	VEHD	VEHD	LGHT	COLL	MANV	MANV	PPA	PPA	PPL	PPL
09	01	09	09	12	04	01	08	01	99	01	99	01	01	13	01	01	99	99	09	09

INVESTIGATING AGENCY: ILLINOIS STATE POLICE
DAMAGE TO ANY ONE PERSON'S VEHICLE / PROPERTY: ☐ $500 OR LESS ☐ $501 - $1,500 ☒ OVER $1,500
TYPE OF REPORT: 1 On-scene
TYPE OF CRASH: B Injury
AGENCY CRASH REPORT NO.: 11-09-00870
ADDRESS NO.:
HIGHWAY or STREET NAME: INTERSTATE 55 SB
☐ City ☒ Township: HAMEL TWP
INTERSECTION RELATED: ☐ Yes ☒ No
PRIVATE PROPERTY: ☐ Yes ☒ No
HIT & RUN: ☐ Yes ☒ No
DATE OF CRASH: 04/25/2009
TIME OF CRASH: 12:46PM
LARS CODE:
0.35 FT / MI N E S W — MILE POST 27 (NAME OF INTERSECTION OR ROAD FEATURE)
☐ AT INTERSECTION WITH
COUNTY: MADISON
CIRCLE DAY OF WEEK: SU MO TU WE TH FR SA
NUMBER MOTOR VEHICLES INVLD: 2

Unit 1
NAME: ☒ DRIVER — CROWSON, ERNEST B
DATE OF BIRTH: 04/13/1939
MAKE: CHEVROLET MODEL: APV-VENTURE YEAR: 1999
STREET ADDRESS: 5504 HAMILTON
SEX: M SAFT: 02 AIR: 09
PLATE NO.: FB8P2X STATE: MO YEAR: 2011
CITY: SAINT LOUIS STATE: MO ZIP: 63136
INJURY: K EJECT: 01
VIN: 1GNDX03E3XD189239
DAMAGED AREA(S): 00 - NONE; 10 - UNDER CARRIAGE; ☒ 11 - TOTAL (ALL AREAS); 12 - OTHER; 99 - UNKNOWN
POINT OF FIRST CONTACT: 01
TOWED: ☒ Y; FIRE: ☒ Y; HAZMAT SPILL: ☒ N; COMVEH: ☒ N
TELEPHONE: (314) 381-3417
DRIVER LICENSE NO.: S137094004
STATE: MO CLASS: F
VEHICLE OWNER (LAST, FIRST, MI): CROWSON, ERNEST B
INSURANCE CO.: GEICO Casualty Company
TAKEN TO: Anderson Hospital-Maryville
EMS AGENCY: Madison Co Coroner
OWNER ADDRESS (STREET, CITY, STATE, ZIP): 5504 HAMILTON SAINT LOUIS, MO 63136
TELEPHONE: (314) 381-3417
POLICY NO.: 4011-26-65-35

Unit 2
NAME: ☒ DRIVER — BOLINE, GEORGIA A
DATE OF BIRTH: 12/12/1949
MAKE: MACK TRUCKS, IN TRUCK YEAR: 9
STREET ADDRESS: 1935 N 32ND ST
SEX: F SAFT: 02 AIR: 04
PLATE NO.: P385328 STATE: IL YEAR: 2009
CITY: DECATUR STATE: IL ZIP: 62526
INJURY: C EJECT: 01
VIN: 1M1AW02Y49N009158
DAMAGED AREA(S): 00 - NONE; 10 - UNDER CARRIAGE; 11 - TOTAL (ALL AREAS); 12 - OTHER; 99 - UNKNOWN
POINT OF FIRST CONTACT: 02
TOWED: ☒ Y; FIRE: ☒ N; HAZMAT SPILL: ☒ N; COMVEH: ☒ Y
TELEPHONE: UNK
DRIVER LICENSE NO.: B450-2814-9953
STATE: IL CLASS: A*
VEHICLE OWNER (LAST, FIRST, MI): ADM, TRUCKING INC
INSURANCE CO.: Gallant Insurance Company
TAKEN TO: Anderson Hospital-Maryville
EMS AGENCY: Edwardsvile Ambulance
OWNER ADDRESS (STREET, CITY, STATE, ZIP): 4666 FARIES PARKWAY DECATUR, IL 62525
TELEPHONE: UK
POLICY NO.: UNK

UNIT	SEAT	DOB	SEX	SAFT	AIR	INJ	EJCT	PASSENGERS & WITNESSES ONLY (NAME, ADDR, TEL)	HOSP	EMS
W		09/20/1958	M					SMITH, DALE D 10928 AVENAL ST HESPERIA, CA 92344 (760) 694-2368		
W		12/31/1948	M					BARRIE, FRED R 1301 PEACHTREE DR VALPARAISO, IN 46383 (219) 462-1039		
W		02/13/1984	F					DICKERSON, DESREE N 1109 EKSTAM DR APT 101 BLOOMINGTON, IL 61704 (314) 381-3417		
W		03/23/1961	M					WISDOM, ANDREW M 1909 S ASHLAND CHICAGO, IL 60608 (312) 401-0663		
W		04/04/1955	M					NOVARIO, MICHAEL D 505 WELLESLEY NORMAL, IL 61761 (309) 452-3166		

Unit	EVNO	MOST	EVNT	LOC
1	1	☐	1	2
1	2	☒	11	1
1	3	☐		
2	1	☒	11	1
2	2	☐		
2	3	☐		

DAMAGE PROPERTY OWNER NAME:
DAMAGED PROPERTY:
PROPERTY OWNER ADDRESS (STREET, CITY, STATE, ZIP):
CONTRIBUTORY CAUSE(S) — PRIMARY: 20 Improper lane usage; SECONDARY: 18 Unable to determine
POSTED SPEED LIMIT:
ARREST NAME: SECTION: CITATION NO.:
ARREST NAME: SECTION: CITATION NO.:
DATE NOTIFIED: 04/25/2009 TIME NOTIFIED: 12:49PM
OFFICER ID: 4643 SIGNATURE: BEAT / DIST: 11 SUPERVISOR ID:
COURT DATE: COURT TIME:

TRFW	VEHT	VEHT	# LANES	ALGN	RSUR	VEHU	VEHU	RDEF	BAC	BAC	# OCCS	# OCCS	DIRP	DIRP
02	03	07	04	01	01	02	20	01	98	98	1	1	05	01

SR 1050 JANUARY 2009 (MCR)

Figure A.1. Sample of Collected Police Reports

200901071421
PoliceReport

04412927

DIAGRAM

NO DIAGRAM

NARRATIVE (Refer to vehicle by Unit No.)

Unit #1 was southbound on Interstate 55. Unit #2 was northbound on Interstate 55 in the right lane. For an unknown reason unit #1 crossed the grass median and entered the northbound lanes. There were only two tire marks in the grass median indicating unit #1 was not rotating as the vehicle traveled through the median. Driver #2 steered to the left in an attempt to avoid unit #1. The right side of unit #1 struck the right side of unit #2. The two vehicle continued side swiping until unit #1 reached the axles of the semi trailer unit #2 was pulling. The front of unit #1 then struck the axles on the semi trailer (IL Reg. T55980). Unit #1 rotated about 90 degrees clockwise and came to rest with the front tires on the east shoulder of the northbound lane and the rear tires in the grass on the east side of the interstate. Unit #1 caught on fire. Driver #1 remained in the vehicle. Unit #2 came to rest in the left northbound lane of Interstate 55.

LOCAL USE ONLY

U1 Color: Unknown	U1 Towed By / To: ADR Inc-Troy / ADR Inc-Troy
U2 Color: White	U2 Towed By / To: ADR Inc-Troy / ADR Inc-Troy

COMMERCIAL VEHICLE — Unit 1

CARRIER NAME
ADDRESS
CITY STATE ZIP

SOURCE: SIDE OF TRUCK / PAPERS / DRIVER / LOG BOOK

ID Number:
USDOT ICCMC
OR State No. State Name None
GVWR

HAZARDOUS MATERIALS PLACARDED ?
IF YES: 4 DIGITS 1 DIGIT Name

HAZARDOUS CARGO RELEASED FROM TRUCK? N
VIOLATION OF HAZMAT REGS. CONTRIBUTE TO CRASH?
VIOLATION OF MCS REGS CONTRIBUTE TO CRASH?
INSPECTION FROM COMPLETED?
HAZMAT OUT OF SERVICE?
MCS OUT OF SERVICE?
FORM NO.

IDOT PERMIT# WideLoad

TRAILER WIDTH(S) TRAILER 1 TRAILER 2	TRAILER LENGTH(S) TRAILER 1 TRAILER 2	Vehicle Length Total - Ft No Of Axles
Vehicle Configuration	Cargo Body Type	LoadType

COMMERCIAL VEHICLE — Unit 2

CARRIER NAME: ADM TRUCKING INC
ADDRESS: 4666 FARIES PARKWAY
CITY STATE ZIP: DECATUR IL 62525

SOURCE: X SIDE OF TRUCK / PAPERS / DRIVER / LOG BOOK

ID Number:
USDOT 238954 ICCMC
OR State No. State Name IL
GVWR 80000

HAZARDOUS MATERIALS PLACARDED ? Y
IF YES: 4 DIGITS 19 1 DIGIT 03 Name ETHONOL

HAZARDOUS CARGO RELEASED FROM TRUCK? N
VIOLATION OF HAZMAT REGS. CONTRIBUTE TO CRASH? N
VIOLATION OF MCS REGS CONTRIBUTE TO CRASH? N
INSPECTION FROM COMPLETED?
HAZMAT N OUT OF SERVICE? N
MCS N OUT OF SERVICE? N
FORM NO. IL3551003808

IDOT PERMIT# WideLoad N

TRAILER WIDTH(S) TRAILER 1 0-96" TRAILER 2	TRAILER LENGTH(S) TRAILER 1 53 TRAILER 2	Vehicle Length Total - Ft 70 No Of Axles 5
Vehicle Configuration 08	Cargo Body Type 03	LoadType 05

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Figure A.1 (continued). Sample of Collected Police Reports

APPENDIX B
NATIONAL AND IDOT SURVEY QUESTIONS AND RESPONSES

B.1 NATIONAL SURVEY QUESTIONS AND RESPONSES

1: Please indicate the level of Need from using flaggers in freeway and expressway.

	No Need 0.0	0.25	Moderate Need 0.5	0.75	Greatest Need 1.0	Responses
Alert road users approaching the work zone	60.0% 12	20.0% 4	5.0% 1	5.0% 1	10.0% 2	20
Slow the speed of oncoming traffic	50.0% 10	25.0% 5	10.0% 2	5.0% 1	10.0% 2	20
Warn workers of errant drivers and vehicle intrusion into work zone	45.0% 9	30.0% 6	0.0% 0	10.0% 2	15.0% 3	20
Direct traffic when construction trucks enter the work zone	30.0% 6	25.0% 5	40.0% 8	5.0% 1	0.0% 0	20
Direct traffic when construction trucks exit the work zone	40.0% 8	35.0% 7	20.0% 4	5.0% 1	0.0% 0	20

Other flagger functions: Please specify the type and level of need for any other flagger functions that are not listed in the table.

State	Response
Florida	FDOT does not allow the use of flaggers on freeways and expressways.
Minnesota	We Don't Usually Use Flaggers On Expressways Or Freeways. Rarely They Will Wave A Slow Paddle When A Truck Exits. State Patrol Is Used When A Roadway Is Closed But Haul Trucks Need To Enter.
Michigan	We Don't allow traffic regulators on the interstate in Michigan. We do have non-freeway that is posted at 55 mph.
Virginia	We only flag on ramps or the roads under/above an Interstate. We do

State	Response
	not flag on Interstates with the possible exception for incident management.

2. Please indicate the level of benefit gained from using flaggers in freeway and expressway work zones with speed limits greater than 40 mph.

	No Benefit 0.0	0.25	Moderate Benefit 0.5	0.75	Greatest Benefit 1.0	Responses
Improve workers safety	45.0% 9	20.0% 4	20.0% 4	5.0% 1	10.0% 2	20
Enhance safety of trucks entering work zone	35.0% 7	25.0% 5	35.0% 7	0.0% 0	5.0% 1	20
Improve safety of trucks exiting work zone	40.0% 8	35.0% 7	20.0% 4	0.0% 0	5.0% 1	20
Enhance road users safety	35.0% 7	15.0% 3	35.0% 7	10.0% 2	5.0% 1	20
Improve traffic mobility	55.0% 11	5.0% 1	30.0% 6	5.0% 1	5.0% 1	20
Improve compliance with traffic speed limit	60.0% 12	10.0% 2	20.0% 4	10.0% 2	0.0% 0	20

Other benefits: Please specify the type and level of any other flagger benefits that are not listed in the table.

State	Response
Virginia	We do not flag on Interstates.
Florida	FDOT does not allow the use of flaggers on freeways and expressways.
Minnesota	We would prefer an intelligent work zone solution to using a human. "Trucks entering/exiting when flashing" has been used with sensors to activate the flashing lights with some success.
Michigan	When used correctly they provide a safe flow of traffic around the work zone. Better and cheaper than a Temp signal.

3. Please indicate the level of risk/hazard caused by using flaggers in freeway and expressway work zones with speed limits greater than 40 mph.

	Lowest Risk 0.0	0.25	Moderate 0.5	0.75	Highest Risk 1.0	Responses
Exposure of flagger to traffic hazards and injuries	5.0% 1	5.0% 1	15.0% 3	10.0% 2	65.0% 13	20
Exposure of flagger to work zones hazards and injuries	5.0% 1	20.0% 4	20.0% 4	10.0% 2	45.0% 9	20
Flagger causing excessive slowdown of traffic & increasing traffic backups	20.0% 4	10.0% 2	35.0% 7	10.0% 2	25.0% 5	20
Flaggers encroaching into open traffic lanes	10.0% 2	5.0% 1	5.0% 1	40.0% 8	40.0% 8	20

Other risks: Please specify the type and level of flagger risks that are not listed in the table

State	Response
Florida	FDOT does not allow the use of flaggers on freeways and expressways.
Mississippi	Pedestrians struck by vehicles traveling in excess of 40mph are injured 15% of the time and killed 85% of the time, statistically speaking.
Minnesota	We would prefer not to use a flagger unless they are actually controlling traffic, not just to slow traffic which can be done with static or dynamic signs.

4. Please indicate the level of risk/hazard to flaggers in the following work zone conditions

	Lowest Risk 0.0	0.25	Medium Risk 0.5	0.75	Highest Risk 1.0	Responses
Curves	0.0% 0	0.0% 0	20.0% 4	50.0% 10	30.0% 6	20
Hills	0.0% 0	0.0% 0	20.0% 4	50.0% 10	30.0% 6	20
Daytime work zones	10.0% 2	15.0% 3	55.0% 11	15.0% 3	5.0% 1	20
Nighttime work zones	0.0% 0	0.0% 0	15.0% 3	30.0% 6	55.0% 11	20
Glare from sun	0.0% 0	5.0% 1	35.0% 7	50.0% 10	10.0% 2	20
Glare from vehicle headlights	0.0% 0	15.0% 3	40.0% 8	30.0% 6	15.0% 3	20
Glare from nighttime work zone lighting	0.0% 0	15.0% 3	45.0% 9	20.0% 4	20.0% 4	20
Adverse weather conditions	5.0% 1	15.0% 3	25.0% 5	40.0% 8	15.0% 3	20
Lack of visibility due to construction-related dust or temporary	10.0% 2	35.0% 7	30.0% 6	20.0% 4	5.0% 1	20

structures						

5. Please indicate the level of need for the following potential spotter functions in freeway and expressway work zones with speed limits greater than 40 mph.

	No Need 0.0	0.25	Moderate Need 0.5	0.75	Greatest Need 1.0	Responses
Warn workers of oncoming traffic	27.8% 5	22.2% 4	22.2% 4	16.7% 3	11.1% 2	18
Detect errant drivers and warn workers using effective warning devices	27.8% 5	22.2% 4	22.2% 4	16.7% 3	11.1% 2	18
Warn workers of construction equipment hazards in the work zone	11.8% 2	35.3% 6	23.5% 4	11.8% 2	17.6% 3	17
Guide trucks/equipment entering the work zone	17.6% 3	35.3% 6	11.8% 2	29.4% 5	5.9% 1	17
Guide trucks/equipment exiting the work zone	29.4% 5	41.2% 7	5.9% 1	23.5% 4	0.0% 0	17

Other spotter functions: Please specify the type and level of need for any other potential spotter functions that are not listed in the table

State	Response
Florida	FDOT Standards does not require a spotter, but contractors elect to use one as needed.
Virginia	I have no knowledge of the construction activities noted in the last three questions in this section. This is typically the responsibility of the contractor.
Minnesota	Our workers are in marked work zones so spotters are not usually used. They are used for backing up trucks such as haul trucks backing up to the paver.

6. Please indicate the level of potential benefits that can be gained from using spotters in expressway and freeway work zones with speed limits greater than 40 mph.

	No Benefit 0.0	0.25	Moderate Benefit 0.5	0.75	Greatest Benefit 1.0	Responses
Improve workers safety	11.1% 2	22.2% 4	33.3% 6	16.7% 3	16.7% 3	18
Enhance safety of trucks entering work zone	22.2% 4	33.3% 6	5.6% 1	22.2% 4	16.7% 3	18
Improve safety of trucks exiting work zone	33.3% 6	27.8% 5	16.7% 3	16.7% 3	5.6% 1	18
Enhance road users safety	50.0% 9	16.7% 3	5.6% 1	16.7% 3	11.1% 2	18
Improve traffic mobility	66.7% 12	16.7% 3	5.6% 1	11.1% 2	0.0% 0	18

Other benefits: Please specify the type and level of any spotter benefits that are not listed in the table

	Response
Minnesota	At high speeds, bad things can happen to quickly for a spotter to make a difference. They may have some benefit in spotting gaps for trucks to enter when leaving the WZ.

7. Please indicate the level of potential risks that can be caused by using spotters in freeway and expressway work zones with speed limits greater than 40 mph.

	Lowest Risk 0.0	0.25	Moderate 0.5	0.75	Highest Risk 1.0	Responses
Exposure of spotter to traffic hazards and injuries	0.0% 0	18.8% 3	18.8% 3	18.8% 3	43.8% 7	16
Exposure of workers to traffic hazards	6.3% 1	18.8% 3	31.3% 5	25.0% 4	18.8% 3	16

Other Risks: Please specify the type and level of any other spotter risks that are not listed in the table

State	Response
Mississippi	Pedestrians struck by vehicles traveling in excess of 40mph are injured 15% of the time and killed 85% of the time, statistically speaking.
Minnesota	Again, we would prefer to use static or portable changeable warning signs to alert the drivers to potential hazards.

8. Does your DOT allow or recommend using of spotters to warn workers from errant drivers in freeway and expressway work zones with speed limits greater than 40 mph.

Answer	Count	Percent
Yes	5	33.3%
No	10	66.7%

Additional comments

Response
We allow/recommend traffic spotters on freeway/expressway/Interstates on a case-by-case basis.
We would rather try to communicate with drivers by static or portable changeable message signs.
I will ask someone from the maintenance perspective (I am construction) to take the survey too. You may get different answers.
FDOT Standards does not require the use of spotters, but contractors are allowed to use them if needed.

9. Based on the collective experience in your DOT, please indicate the level of effectiveness of using spotters to perform the following functions instead of flaggers in the following work zone layouts in freeway and expressway work zones with speed limits greater than 40 mph.

	Least Effective 0.0	0.25	Moderate Effectiveness 0.5	0.75	Most Effective 1.0	Responses
Alert oncoming traffic & reduce its speed	0.0% 0	0.0% 0	0.0% 0	0.0% 0	0.0% 0	0
Warn workers of oncoming traffic	27.3% 3	9.1% 1	36.4% 4	9.1% 1	18.2% 2	11
Detect errant drivers and warn workers using effective warning devices	18.2% 2	27.3% 3	18.2% 2	27.3% 3	9.1% 1	11
Warn workers of the hazards posed by construction equipment/ trucks in the work zone	9.1% 1	27.3% 3	36.4% 4	18.2% 2	9.1% 1	11
Guide entering trucks and other construction equipment to work zone	36.4% 4	36.4% 4	9.1% 1	9.1% 1	9.1% 1	11
Guide exiting trucks and other construction equipment from work zone	27.3% 3	36.4% 4	9.1% 1	9.1% 1	18.2% 2	11

10. Based on the collective experience in your DOT, please indicate the level of effectiveness of using spotters instead of flaggers to accomplish the following safety and mobility goals in freeway and expressway work zones with speed limits greater than 40 mph.

	Least Effective 0.0	0.25	Moderate Effectiveness 0.5	0.75	Most Effective1.0	Responses
Improve flagger and/or spotter safety	45.5% 5	18.2% 2	27.3% 3	9.1% 1	0.0% 0	11
Enhance workers safety	18.2% 2	18.2% 2	27.3% 3	9.1% 1	27.3% 3	11
Improve road users safety	45.5% 5	18.2% 2	18.2% 2	18.2% 2	0.0% 0	11
Enhance traffic mobility	54.5% 6	27.3% 3	9.1% 1	9.1% 1	0.0% 0	11
Enhance work zone access and egress	36.4% 4	18.2% 2	18.2% 2	18.2% 2	9.1% 1	11

11. Based on the collective experience in your DOT, please indicate the impact of using spotters instead of flaggers in the following work zone layouts in freeways and expressways with speed limits greater than 40 mph.

	Negative Impact 0.0	0.25	No Impact	0.75	Positive Impact 1.0	Responses
Very short duration work zone < 15min	0.0% 0	0.0% 0	45.5% 5	9.1% 1	45.5% 5	11
Short duration work zones	0.0% 0	0.0% 0	45.5% 5	18.2% 2	36.4% 4	11
Long duration work zones	0.0% 0	20.0% 2	40.0% 4	40.0% 4	0.0% 0	10
Lane closure at enter/exit ramp	0.0% 0	18.2% 2	45.5% 5	36.4% 4	0.0% 0	11
One lane closure on highway	0.0% 0	9.1% 1	54.5% 6	36.4% 4	0.0% 0	11
Two lane closure on highway	0.0% 0	9.1% 1	54.5% 6	36.4% 4	0.0% 0	11
Median crossover	0.0% 0	0.0% 0	0.0% 0	0.0% 0	0.0% 0	0
Use of shoulder	0.0% 0	0.0% 0	0.0% 0	0.0% 0	0.0% 0	0
Ramps	0.0% 0	0.0% 0	0.0% 0	0.0% 0	0.0% 0	0
Lane closure with Truck Mounted Attenuator (TMA)	0.0% 0	0.0% 0	63.6% 7	36.4% 4	0.0% 0	11
Lane closure on freeways with low Average Annual Daily Traffic (AADT)	0.0% 0	9.1% 1	63.6% 7	27.3% 3	0.0% 0	11
Lane closure on freeways with high Average Annual Daily Traffic (AADT)	0.0% 0	9.1% 1	54.5% 6	36.4% 4	0.0% 0	11

12. When spotters are used instead of flaggers in freeway and expressway work zones with speed limits greater than 40 mph, please indicate the level of effectiveness of the following measures to maximize work zone safety and mobility.

	Least Effective 0.0	0.25	Moderate Effectiveness 0.5	0.75	Most Effective 1.0	Responses
Locate spotters in safe areas away from the hazards of oncoming traffic	0.0% 0	9.1% 1	27.3% 3	9.1% 1	54.5% 6	11
Plan a safe escape route for spotters	0.0% 0	0.0% 0	18.2% 2	18.2% 2	63.6% 7	11
Use effective noise makers such as air horn to warn workers of hazards	0.0% 0	36.4% 4	18.2% 2	18.2% 2	27.3% 3	11
Alert motorists about work zones access/egress points	18.2% 2	36.4% 4	18.2% 2	9.1% 1	18.2% 2	11
Use automated intrusion alarm system	18.2% 2	45.5% 5	18.2% 2	9.1% 1	9.1% 1	11
Use radar trailer to inform oncoming drivers of their speed	0.0% 0	9.1% 1	18.2% 2	27.3% 3	45.5% 5	11
Use sequential work zone taper warning lights	20.0% 2	30.0% 3	30.0% 3	20.0% 2	0.0% 0	10
Use automated lane closure systems	10.0% 1	40.0% 4	40.0% 4	10.0% 1	0.0% 0	10
Use Automated Flagger Assistance Devices (AFADs)	0.0% 0	0.0% 0	0.0% 0	0.0% 0	0.0% 0	0
Deploy back up alarms for backing trucks in the work zone	0.0% 0	9.1% 1	9.1% 1	36.4% 4	45.5% 5	11

13. Please indicate the level of effectiveness of the following measures to improve the safety of access and egress points in a freeway and expressway work zones with speed limits greater than 40 mph.

	Least Effective 0.0	0.25	Moderate Effectiveness 0.5	0.75	Most Effective	Responses
Deploy spotter to assist vehicles in entering and exiting work zone	9.1% 1	36.4% 4	18.2% 2	18.2% 2	18.2% 2	11
Deploy flagger to assist vehicles in entering and exiting work zone	16.7% 2	25.0% 3	25.0% 3	16.7% 2	16.7% 2	12
Equip the rear of construction vehicles entering the work zone with a warning sign such as "Construction Vehicle Do Not Follow"	8.3% 1	25.0% 3	16.7% 2	25.0% 3	25.0% 3	12
Equip construction vehicles with high intensity rotating or flashing light	8.3% 1	0.0% 0	16.7% 2	50.0% 6	25.0% 3	12
Improve lighting and visibility of access/egress points during nighttime work zones	0.0% 0	8.3% 1	25.0% 3	33.3% 4	33.3% 4	12
Incorporate access/egress into Internal Traffic Control Plans (ITCPs)	0.0% 0	9.1% 1	0.0% 0	36.4% 4	54.5% 6	11

Use temporary rumble strips	18.2% 2	27.3% 3	27.3% 3	18.2% 2	9.1% 1	11
Use larger and additional warning signs	9.1% 1	18.2% 2	45.5% 5	9.1% 1	18.2% 2	11
Build temporary ramp to provide median access from street overpass	0.0% 0	10.0% 1	0.0% 0	50.0% 5	40.0% 4	10
Use ITS technology to improve access/egress safety	0.0% 0	16.7% 2	25.0% 3	33.3% 4	25.0% 3	12

14. Please indicate which of the following temporary traffic control measures has been deployed or recommended in your DOT for work zones on freeway and expressway with speed limits greater than 40 mph.

Device	Responses
Intrusion Alarms	2
Portable Changeable Massage Signs (PCMS)	16
Temporary Rumble Strips	13
Speed Displays	14
Truck mounted Attenuators	14
Police Patrol	14
Radar Drones	2
Automatic Flagger Assistant Device (AFAD)	6
Mobile Barriers	8

15. Please indicate the level of effectiveness of the following Temporary Traffic Control (TTC) devices to improve safety in freeway and expressway work zones with speed limits greater than 40 mph.

	Least Effective 0.0	0.25	Moderate Effectiveness 0.5	0.75	Most Effective 1.0	Responses
Intrusion Alarms	60.0% 6	10.0% 1	20.0% 2	0.0% 0	10.0% 1	10
Portable Changeable Massage Signs (PCMS)	0.0% 0	0.0% 0	0.0% 0	56.3% 9	43.8% 7	16
Dynamic Message Boards	0.0% 0	0.0% 0	0.0% 0	0.0% 0	0.0% 0	0
Temporary rumble strips	6.7% 1	0.0% 0	26.7% 4	46.7% 7	20.0% 3	15
Portable Speed Monitor Displays (PSMD)	0.0% 0	0.0% 0	60.0% 9	13.3% 2	26.7% 4	15
Truck Mounted Attenuators (TMAs)	0.0% 0	0.0% 0	6.3% 1	31.3% 5	62.5% 10	16
Police Patrol	0.0% 0	7.1% 1	7.1% 1	21.4% 3	64.3% 9	14
Automated Flagger Assistance Devices (AFADs)	0.0% 0	0.0% 0	0.0% 0	0.0% 0	0.0% 0	0
Radar Drones	42.9% 3	42.9% 3	14.3% 1	0.0% 0	0.0% 0	7
Automatic Flagger Assistant Device (AFAD)	27.3% 3	27.3% 3	9.1% 1	18.2% 2	18.2% 2	11
Mobile Barrier	0.0% 0	0.0% 0	27.3% 3	27.3% 3	45.5% 5	11

16. Please list any new traffic control devices or technologies that can be used to improve work zone safety and mobility in freeway and expressway work zones with speed limits greater than 40 mph.

Response
Stopped traffic advisory systems. Provide real time back-up alerts and messages.
We have been utilizing iCone on a few projects to track queuing.
Web based speed monitoring devices (iCone, SmartCone, etc.)
mobile barrier & work zone ITS such as queue detection
We have implemented sequential lighting for nighttime work. These lights have shown a larger amount of the traveling public will merge sooner during nighttime projects.
Our metro district often closes a section of freeway on weekends for paving and related work. Other freeways are the detour and with lower weekend traffic volumes, backups are not too bad, there is a lot of media publicity, and the public seems to accept it as the work gets done quicker.

17. Please feel free to add any other comments on the use of spotter and/or flagger to improve freeway and expressway work zones safety and mobility with speed limits greater than 40 mph.

Response
Don't.
Spotters should only be used as a last resort or for short duration work zones. Flaggers should not be used as a traffic control method under the above mentioned application.
In Missouri, we do not use spotters or flaggers on freeway/expressway work zones. We will allow contractors to use them on some projects, upon request. The major concerns is usually a lone person in the work zone area and many will stand very close to the open lane to try to slow people down. This may cause the traveling public to slow down excessively and then you may have a queuing concern and potential of rear end accidents. How does the spotter or flagger know the traveling public is going over the speed limit? Several times the flagger will motion to slow down even though the public is traveling the speed limit or slower.

Response
The spotter is most effective when working next to or in the barrel line. Pavement marking operations which tend to be closer to the traffic than other operations has the largest benefit.
Questions 9 through 13 were not answered because we do not conduct flagging operations on freeway/expressway/Interstates roadways.

D.2 IDOT SURVEY QUESTIONS AND RESPONSES

1. Please indicate the level of need for the following flagger functions in freeway and expressway work zones with speed limits greater than 40 mph.

	No Need 0.0	0.25	Moderate Need 0.5	0.75	Greatest Need 1.0	Responses
Alert road users approaching the work zone	17.5% 14	6.3% 5	17.5% 14	11.3% 9	47.5% 38	80
Slow the speed of oncoming traffic	5.0% 4	8.8% 7	10.0% 8	13.8% 11	62.5% 50	80
Warn workers of errant drivers and vehicle intrusion into work zone	8.8% 7	2.5% 2	11.3% 9	17.5% 14	60.0% 48	80
Direct traffic when construction trucks enter the work zone	7.5% 6	10.0% 8	16.3% 13	21.3% 17	45.0% 36	80
Direct traffic when construction trucks exit the work zone	6.3% 5	8.9% 7	20.3% 16	21.5% 17	43.0% 34	79

Other flagger functions: Please specify the type and level of need for any other flagger functions that are not listed in the table

Response
Loud noise, excessive dirt
Protect other passing motorists from excessive speed
It is to unsafe to have a flagger standing out there at high speeds !
Stopping traffic for equipment movement & materials thru out projects. Alert traffic to temporary job site hazards.
What does direct traffic mean? The main job for a flagger is to slow traffic when trucks are leaving or entering work zone. Not to redirect traffic.
1) To alert motorist and protect workers WITHIN the work zone when the work operations are spread out, i.e. patching, HMA placement.
Give a presence to the traveling public, especially motorists who don't shy from the edge of the closed lane and work is along or beyond that edge of the work lane, the flagger can give a waving motion to push traffic over. Need 1.0.
Spotters needed for directing construction trucks. (Flaggers are not needed to direct interstate traffic.) All answers assume the work area is not behind temporary barrier.

2. Please indicate the level of benefit gained from using flaggers in freeway and expressway work zones with speed limits greater than 40 mph.

	No Benefit 0.0	0.25	Moderate Benefit 0.5	0.75	Greatest Benefit 1.0	Responses
Improve workers safety	6.3% 5	8.8% 7	15.0% 12	17.5% 14	52.5% 42	80
Enhance safety of trucks entering work zone	8.9% 7	10.1% 8	30.4% 24	15.2% 12	35.4% 28	79
Improve safety of trucks exiting work zone	5.0% 4	12.5% 10	32.5% 26	15.0% 12	35.0% 28	80
Enhance road users safety	7.5% 6	13.8% 11	23.8% 19	17.5% 14	37.5% 30	80
Improve traffic	21.3%	12.5%	23.8%	11.3%	31.3%	80

mobility	17	10	19	9	25	
Improve compliance with traffic speed limit	21.5% 17	13.9% 11	22.8% 18	13.9% 11	27.8% 22	79
Flaggers encroaching open traffic lanes	0.0% 0	0.0% 0	0.0% 0	0.0% 0	0.0% 0	0
Compliance with traffic speed limit	0.0% 0	0.0% 0	0.0% 0	0.0% 0	0.0% 0	0

Other benefits: Please specify the type and level of any other flagger benefits that are not listed in the table

Response
All answers assume the work area is not behind temporary barrier.
They provide the eyes that other people may not be able to do as they are busy performing tasks.
it’s just another body put at unneeded risk
1) Flaggers are often used to shift traffic over in moving operations, but the motorists are not informed by signing this is the situation. When this happens, traffic mobility is substantially impacted in a negative way because of traffic suddenly slowing to accommodate the situation. 2) Flaggers are ignored by the motoring public with respect to slowing traffic unless they physically stand in the live lane. The only thing that seems to help slow traffic down and keep the flagger out of harm’s way is a very visible police presence. Photo enforcement doesn't slow down traffic, just more speeding tickets are issued.
Flaggers tend to defeat mobility and work zone speed limits by over-aggressive actions; pushing traffic into the shoulder, demanding speeds much less than the work zone speed limit.
Flaggers do not seem to have an effect on the motorists' perception of need to comply with work zone speed limits. More enforcement is needed and should be a part of the project plan.

3. Please indicate the level of risk/hazard caused by using flaggers in freeway and expressway work zones with speed limits greater than 40 mph

	Lowest Risk 0.0	0.25	Moderate 0.5	0.75	Highest Risk 1.0	Responses
Exposure of flagger to traffic hazards and injuries	2.6% 2	6.4% 5	14.1% 11	17.9% 14	59.0% 46	78
Exposure of flagger to work zones hazards and injuries	11.5% 9	14.1% 11	35.9% 28	15.4% 12	23.1% 18	78
Flagger causing excessive slow down of traffic & increasing traffic backups	16.7% 13	15.4% 12	12.8% 10	25.6% 20	29.5% 23	78
Flaggers encroaching into open traffic lanes	11.5% 9	14.1% 11	12.8% 10	20.5% 16	41.0% 32	78

Other risks: Please specify the type and level of flagger risks that are not listed in the table

Response
All answers assume the work area is not behind temporary barrier.
1) Contractors use flaggers improperly by having them stop traffic in non-emergency situations for contractor convenience to move material or equipment within the work zone which generally causes incidents as this is unexpected by the motoring public. When they see speed signs up stating a speed limit, they expect to be able to go through the work zone at that speed. 2) Flaggers are often used to solve all of the contractors' errors in planning to handle traffic issues, many times with too few of them strictly because of cost. Our only recourse is to issue TC Deficiencies, but it doesn't address the issues at hand, it just fines the contractor.
this stuff sounds good on paper but the people standing out there would disagree please don't put me at unneeded risk I have kids
Aggressive flaggers are pushing well into the traveled lane, risking themselves and interrupting traffic flow - which can lead to rear end crashes.
Flaggers propose zero risks. Traffic is slower when a flagger is present when compared to not being present.
There is an increase level of traffic accidents when flaggers try to slow down traffic too much on freeways.

4. Please indicate the level of risk/hazard to flaggers in the following work zone-conditions.

Work Zone-Condition	Lowest Risk 0.0	0.25	Medium Risk 0.5	0.75	Highest Risk1.0	Responses
Curves	1.3% 1	1.3% 1	8.8% 7	40.0% 32	48.8% 39	80
Hills	1.3% 1	1.3% 1	5.1% 4	39.2% 31	53.2% 42	79
Daytime work zones	14.1% 11	24.4% 19	39.7% 31	15.4% 12	6.4% 5	78
Nighttime work zones	1.3% 1	5.1% 4	13.9% 11	27.8% 22	51.9% 41	79
Glare from sun	5.0% 4	8.8% 7	18.8% 15	31.3% 25	36.3% 29	80
Glare from vehicle headlights	5.1% 4	16.5% 13	31.6% 25	19.0% 15	27.8% 22	79
Glare from nighttime work zone lighting	7.7% 6	12.8% 10	30.8% 24	23.1% 18	25.6% 20	78
Adverse weather conditions	5.1% 4	10.1% 8	15.2% 12	34.2% 27	35.4% 28	79
Lack of visibility due to construction-related dust or temporary structures	8.9% 7	24.1% 19	21.5% 17	20.3% 16	25.3% 20	79

5. Please indicate the level of need for the following potential spotter functions in freeway and expressway work zones with speed limits greater than 40 mph.

	No Need 0.0	0.25	Moderate Need 0.5	0.75	Greatest Need 1.0	Responses
Warn workers of oncoming traffic	13.9% 11	19.0% 15	11.4% 9	13.9% 11	41.8% 33	79
Detect errant drivers and warn workers using effective warning devices	7.6% 6	7.6% 6	8.9% 7	12.7% 10	63.3% 50	79
Warn workers of construction equipment hazards in the work zone	20.3% 16	26.6% 21	20.3% 16	10.1% 8	22.8% 18	79
Guide trucks/equipment entering the work zone	27.8% 22	19.0% 15	20.3% 16	8.9% 7	24.1% 19	79
Guide trucks/equipment exiting the work zone	25.3% 20	22.8% 18	21.5% 17	7.6% 6	22.8% 18	79

Other spotter functions: Please specify the type and level of need for any other potential spotter functions that are not listed in the table

Response
All answers assume the work area is not behind temporary barrier.
Spotters serve no function, they can be as effective as a flagger on site
never observed a spotter in action
someone watching your back would be great
1) Spotters may be helpful in guiding trucks into and out of work zones if there is no real clear path the trucks are to be taking in doing so. Otherwise they will be just one more person 'in the way for a potential incident' 2) For the work crew to actually hear an audible warning from a spotter, is unrealistic because of the noise level in a construction zone. I don't know of any horn or whistle that is loud enough to overcome the noise from driving pile, to scrappers, dozers, and other earth moving equipment operating in the work zone.
I would think spotter is either watching traffic or construction equipment and not both. We have not used one in D3 to my knowledge.

6. Please indicate the level of potential benefits that can be gained from using spotters in expressway and freeway work zones with speed limits greater than 40 mph.

	No Benefit 0.0	0.25	Moderate Benefit 0.5	0.75	Greatest Benefit 1.0	Responses
Improve workers safety	9.0% 7	6.4% 5	19.2% 15	7.7% 6	57.7% 45	78
Enhance safety of trucks entering work zone	20.3% 16	12.7% 10	27.8% 22	17.7% 14	21.5% 17	79
Improve safety of trucks exiting work zone	19.2% 15	12.8% 10	29.5% 23	19.2% 15	19.2% 15	78
Enhance road users safety	24.1% 19	16.5% 13	21.5% 17	12.7% 10	25.3% 20	79
Improve traffic mobility	26.6% 21	20.3% 16	22.8% 18	7.6% 6	22.8% 18	79

7. Please indicate the level of potential risks that can be caused by using spotters in freeway and expressway work zones with speed limits greater than 40 mph.

	Lowest Risk 0.0	0.25	Moderate 0.5	0.75	Highest Risk 1.0	Responses
Exposure of spotter to traffic hazards and injuries	15.2% 12	13.9% 11	30.4% 24	19.0% 15	21.5% 17	79
Exposure of workers to traffic hazards	23.1% 18	16.7% 13	25.6% 20	17.9% 14	16.7% 13	78

8. Please indicate what you believe the level of effectiveness would be if spotters are used to perform the following functions instead of flaggers in freeway and expressway work zones with speed limits greater than 40 mph.

	Least Effective 0.0	0.25	Medium Effectiveness 0.5	0.75	Most Effective 1.0	Responses
Alert oncoming traffic & reduce its speed	0.0% 0	0.0% 0	0.0% 0	0.0% 0	0.0% 0	0
Warn workers of oncoming traffic	12.8% 10	12.8% 10	24.4% 19	14.1% 11	35.9% 28	78
Detect errant drivers and warn workers using effective warning devices	12.8% 10	7.7% 6	20.5% 16	17.9% 14	41.0% 32	78
Warn workers of the hazards posed by construction equipment/ trucks in the work zone	16.7% 13	23.1% 18	37.2% 29	10.3% 8	12.8% 10	78
Guide entering trucks and other construction equipment to work zone	26.9% 21	25.6% 20	28.2% 22	9.0% 7	10.3% 8	78
Guide exiting trucks and other construction equipment from work zone	23.1% 18	28.2% 22	28.2% 22	9.0% 7	11.5% 9	78

9. Please indicate the potential level of effectiveness of using spotters instead of flaggers to accomplish the following safety and mobility goals in freeway and expressway work zones with speed limits greater than 40 mph.

	Least Effective 0.0	0.25	Moderate Effectiveness 0.5	0.75	Most Effective 1.0	Responses
Improve flagger and/or spotter safety	17.7% 14	17.7% 14	13.9% 11	16.5% 13	34.2% 27	79
Enhance workers safety	12.8% 10	16.7% 13	21.8% 17	19.2% 15	29.5% 23	78
Improve road users safety	30.8% 24	20.5% 16	21.8% 17	14.1% 11	12.8% 10	78
Enhance traffic mobility	31.6% 25	16.5% 13	22.8% 18	13.9% 11	15.2% 12	79
Enhance work zone access and egress	27.8% 22	21.5% 17	25.3% 20	13.9% 11	11.4% 9	79

10. Please indicate the potential impact of using spotters instead of flaggers in the following work zone layouts in freeways and expressways with speed greater than 40 mph.

	Negative Impact 0.0	0.25	No Impact	0.75	Positive Impact 1.0	Responses
Very short duration work zone < 15min	11.7% 9	9.1% 7	45.5% 35	11.7% 9	22.1% 17	77
Short duration work zones	11.7% 9	11.7% 9	29.9% 23	29.9% 23	16.9% 13	77
Long duration work zones	15.6% 12	11.7% 9	23.4% 18	19.5% 15	29.9% 23	77
Lane closure at enter/exit ramp	18.4% 14	10.5% 8	25.0% 19	21.1% 16	25.0% 19	76
One lane closure on highway	19.5% 15	10.4% 8	20.8% 16	27.3% 21	22.1% 17	77
Two lane closure on highway	21.1% 16	6.6% 5	26.3% 20	23.7% 18	22.4% 17	76
Median crossover	0.0% 0	0.0% 0	0.0% 0	0.0% 0	0.0% 0	0
Use of shoulder	0.0% 0	0.0% 0	0.0% 0	0.0% 0	0.0% 0	0
Ramps	0.0% 0	0.0% 0	0.0% 0	0.0% 0	0.0% 0	0
Lane closure with Truck Mounted Attenuator (TMA)	14.5% 11	11.8% 9	31.6% 24	23.7% 18	18.4% 14	76
Lane closure on freeways with low Average Annual Daily Traffic (AADT)	13.5% 10	10.8% 8	35.1% 26	28.4% 21	12.2% 9	74
Lane closure on freeways with high Average Annual Daily Traffic (AADT)	16.9% 12	5.6% 4	21.1% 15	22.5% 16	33.8% 24	71

11. If spotters are used instead of flaggers in freeway and expressway work zones with speed limit more than 40 mph, please indicate which of the following measures can be used to maximize work zone safety and mobility.

	Least Effective 0.0	0.25	Moderate Effectivenes s 0.5	0.75	Most Effective 1.0	Responses
Locate spotters in safe areas away from the hazards of oncoming traffic	6.5% 5	5.2% 4	18.2% 14	18.2% 14	51.9% 40	77
Plan a safe escape route for spotters	5.1% 4	2.5% 2	25.3% 20	20.3% 16	46.8% 37	79
Use effective noise makers such as air horn to warn workers of hazards	10.3% 8	6.4% 5	15.4% 12	17.9% 14	50.0% 39	78
Alert motorists about work zones access/egress points	10.3% 8	21.8 % 17	34.6% 27	17.9% 14	15.4% 12	78
Use automated intrusion alarm system	7.9% 6	13.2 % 10	32.9% 25	26.3% 20	19.7% 15	76
Use radar trailer to inform oncoming drivers of their speed	3.8% 3	5.1% 4	23.1% 18	30.8% 24	37.2% 29	78
Use sequential work zone taper warning lights	8.9% 7	10.1 % 8	31.6% 25	29.1% 23	20.3% 16	79
Use automated lane closure systems	14.3% 11	16.9 % 13	28.6% 22	24.7% 19	15.6% 12	77
Use Automated Flagger Assistance Devices (AFADs)	0.0% 0	0.0% 0	0.0% 0	0.0% 0	0.0% 0	0
Deploy back up alarms for backing trucks in the work zone	9.1% 7	7.8% 6	19.5% 15	27.3% 21	36.4% 28	77

12. Please indicate the level of effectiveness of the following measures to improve the safety of access and egress points in a freeway and expressway work zones with speed limits greater than 40 mph.

	Least Effective 0.0	0.25	Moderate Effectiveness 0.5	0.75	Most Effective	Responses
Deploy spotter to assist vehicles in entering and exiting work zone	20.5% 16	15.4% 12	32.1% 25	12.8% 10	19.2% 15	78
Deploy flagger to assist vehicles in entering and exiting work zone	10.3% 8	9.0% 7	30.8% 24	24.4% 19	25.6% 20	78
Equip the rear of construction vehicles entering the work zone with a warning sign such as "Construction Vehicle Do Not Follow"	3.8% 3	14.1% 11	34.6% 27	26.9% 21	20.5% 16	78
Equip construction vehicles with high intensity rotating or flashing light	5.1% 4	7.7% 6	20.5% 16	41.0% 32	25.6% 20	78
Improve lighting and visibility of access/egress points during nighttime work zones	3.9% 3	2.6% 2	13.0% 10	33.8% 26	46.8% 36	77
Incorporate access/egress into Internal Traffic Control Plans (ITCPs)	10.4% 8	2.6% 2	31.2% 24	33.8% 26	22.1% 17	77

Use temporary rumble strips	13.0% 10	10.4% 8	32.5% 25	31.2% 24	13.0% 10	77
Use larger and additional warning signs	14.1% 11	19.2% 15	33.3% 26	17.9% 14	15.4% 12	78
Build temporary ramp to provide median access from street overpass	13.2% 10	22.4% 17	36.8% 28	18.4% 14	9.2% 7	76
Use ITS technology to improve access/egress safety	9.2% 7	19.7% 15	28.9% 22	30.3% 23	11.8% 9	76

13. Please indicate the level of effectiveness of the following Temporary Traffic Control (TTC) devices in freeway and expressway work zones with speed greater than 40 mph.

	Least Effective 0.0	0.25	Moderate Effectiveness 0.5	0.75	Most Effective 1.0	Responses
Intrusion Alarms	10.4% 8	18.2% 14	27.3% 21	27.3% 21	16.9% 13	77
Portable Changeable Massage Signs (PCMS)	0.0% 0	8.9% 7	35.4% 28	25.3% 20	30.4% 24	79
Temporary rumble strips	7.7% 6	10.3% 8	39.7% 31	28.2% 22	14.1% 11	78
Speed Displays	3.8% 3	5.1% 4	19.2% 15	35.9% 28	35.9% 28	78
Truck Mounted Attenuators (TMAs)	1.3% 1	7.7% 6	16.7% 13	43.6% 34	30.8% 24	78
Police Patrol	0.0% 0	1.3% 1	6.3% 5	10.1% 8	82.3% 65	79
Automated Flagger Assistance Devices (AFADs)	0.0% 0	0.0% 0	0.0% 0	0.0% 0	0.0% 0	0

Other devices

Response
Massage Signs or Message Signs?
PERMANENT POLICE PATROL
Police patrol is the most effective and needs to be used more often.

14. Please list any new traffic control devices or technologies that can be used to improve work zone safety and mobility in freeway and expressway work zones with speed greater than 40 mph.

Response
Give the flagger the ability to control drivers or something similar to warn workers
ISP Photo Enforcement Vans deployed within work zones. Trooper in a truck.
Mobile Barrier
SPEED BUMPS
1) Public education in Illinois - Work Zone Speeds are not just when worker are present. 2) Require speed displays in the TCP 3) Require some level of enforcement/police presence in the TCP 4) Develop and enforce penalties for leaving signs up on inactive work zones that should not be there unless work is being performed
Not a device: but I think earlier warning of which lane is being closed would be helpful in high traffic areas
Start notifying traffic to merge up to 3 miles out. We have successfully used a truck mounted message board to travel backwards on shoulder and notify oncoming traffic of delays, stopped traffic, detours, etc.
The best way and probably the only way to slow traffic down is police patrol. The safest work zone is a slow moving one.
Make a device that blocks all cell phone service (in the work zone) in order to cut down on distracted drivers.
Remote controlled flagger stations. Increased use of TMAs - going two wide with one on the shoulder to prevent run-around accidents.
Reflectors on barrels in lieu of lights for overnight closures. Lights burn out, reflectors do not.
Install flashing LED lights on stop/go paddles for better visibility. Batteries could be mounted in handle.
Tall grabber cones, as used in other states, they are easier to see thru when used to delineate exit/entrance ramps. Also, have a smaller foot print, take up less roadway space. Especially when you have to put them in the live lane for HMA paving operations. With drums it forces people to drive on rumble strips and they don't like that.
There are ITS components available, such as barrels, which can relay real-time travel info to motorists on an advanced message board and even GPS units. I think this would be a huge benefit to prevent rear-end collisions from queues.

15. Please feel free to add any other comments on the use of spotter and/or flagger to improve freeway and expressway work zones safety and mobility with speed greater than 40 mph.

Response
Don’t have a person standing out on the highway trying to direct traffic.
Enforce Scotts law with law enforcement get out there and start writing tickets.
Neither should be used at those speeds it is for the TMA to protect the work site.
Flaggers are the safest way to keep workers safe on the roads. They are a crucial piece in working on the highways. They are used more than what people realize and they are trained to do their job.
It is our experience that there are enough warnings/signs/flaggers, the problem is poor/rude/distracted drivers who do not pay attention or are mad/upset and in a hurry and do not think any of the speed limit signs apply to them.
Some flaggers disrupt traffic flow on freeways causing unsafe conditions for motorist. This also can lead to unsafe conditions for the flaggers & workers. Flaggers can also be hard to see in lane closures that require drums or barricades. Mobile message boards relaying messages about construction ahead or trucks entering and leaving may be safer for both the flaggers and the motorist. Speed indicator signs also seem very effective in slowing down traffic.
Police are the best. Flaggers do have a place but offer little in the way of actually alerting workers of hazards. One obstacle is the high noise level and distance of flagger from the workers. I understand the distance but the key component is how to effectively warn the workers where a spotter may be better suited.
Converting flaggers to spotters will require great effort by IDOT. Contractors have become accustomed to using the flagger in an aggressive stance, pushing traffic into the shoulder and slowing traffic - all at great risk to the flagger and traffic.
The spotter is a dumb idea. If a work zone has multiple crews how many spotter do you need? If someone comes through a work zone an alarm goes off, ok then what the crews still have to find the danger and react. My opinion through 25 years + in work zones is it is probably too late.
1) From previous definition, spotters don't have any authority to direct or control traffic. How are they in any way going to guide traffic through a work zone. There only purpose would be to direct the contractors operations inside the work zone, which we already have a project foremen doing this, in theory anyway.
I was unsure what was meant by "replace" flagger with spotter. Does this mean there would be not flagger? In some instances cited this is not even feasible.

Response
I believe there is a great safety benefit for using either in a work zone. Many situations both would be needed at the same time. I feel they provide some of the same as well as different jobs. Flaggers help slow down and control traffic and when a vehicle intrudes the work zone the flagger is concerned with their own safety first which delays them from warning other workers where spotters primary concern is warning workers of pending danger.
A major concern I have is the (mis)use of flaggers for a lane closure on multi-lane facilities. They are only supposed to be there to help the trucks get in and out of the work zone. In reality, all they do is stand in the open lane of traffic, unnecessarily forcing traffic onto the shoulder and slowing it far below the work zone speed limit (as well as exposing the flaggers themselves to oncoming traffic). The result is greatly increased user delays and often the backup extends beyond the traffic control. This is a major cause of totally preventable accidents that often result in multiple fatalities for a function that provides zero benefit.
A flagger is valuable to motorists to alert them of the presence of workers and equipment in high speed work zones. The flagger can also serve as a spotter if they are positioned correctly, which is valuable to workers to alert them of intrusion into the work zone. Flagger equipped with immediate access to air horns or equivalent warning devices can serve as a flagger/spotter and warn both motorists and workers.
Drivers are like sheep. They follow each other. That means they follow the construction vehicle in front of them.
These are all great ideas, but until you start hammering people for breaking the law in work zones, most attempts of safety is worthless.
I would never like to see only a spotter at the workers feel advance warning of flagger is needed also.
Flaggers are very good at getting drivers attention especially when working on centerline and drivers must squeeze the shoulder. A good flagger will command the attention of drivers, even on a busy interstate and thereby the most effective. On the other hand, some flaggers seem to blend into the background and are not effective. Boldness should be a trait of flaggers. I believe a flagger should be equipped with an air horn hanging from their belt to notify workers of an errant driver.